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WESTON CLEAN PAL

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Summary

A new form of PAL coding and decoding is described which gives complete freedom from crosscolour and crossluminance at the expense of introducing some less annoying impairments. It is based on the Weston Y_2, $(U \pm V)$ *digital transmission system. Coarse crosscolour is removed by adding at the coder a signal in antiphase to the luminance components which would cause coarse crosscolour; this antiphase signal cancels out the crosscolour at the decoder. This form of 'clean' PAL coding and decoding is compatible with conventional decoding and coding. Subjective tests are described which show that clean coding in particular gives a worthwhile improvement to colour pictures.*

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WESTON CLEAN PAL

A. Oliphant, M.A., C.Eng., M.I.E.E.

1. Introduction

In a PAL coded television signal, the high frequency part of the signal spectrum is shared between luminance components describing fine detail and the chrominance signal which consists of colour difference signals modulated onto a subcarrier. This band sharing means that there can be crosstalk between the two signals. Crosstalk from chrominance into luminance (known as crossluminance) appears as a fine moving pattern in coloured areas. Crosstalk from luminance into chrominance (known as crosscolour) appears as spurious coloured patterns in areas of fine luminance detail; this is the cause of the coloured patterns which can often be seen on checked and striped clothes. Systems for partly or wholly removing these crosseffects have become known as 'clean' PAL systems.

There are two requirements for an improved 'clean' PAL coding scheme. The first requirement is that the scheme must be capable of producing much better pictures by reducing crosscolour, without compromising on other aspects of picture quality such as resolution of fine luminance detail. New forms of coder and decoder will be more complicated and therefore initially more expensive, so there must be an incentive to change. Improvements to television receivers such as wider i.f. bandwidths and larger display screens, giving the possibility of sharper pictures, must also be considered; any proposed new coding and decoding scheme should be able to exploit these potential improvements.

The second requirement is for compatibility. There are millions of conventional decoders in existing receivers; these must not give worse results if broadcasters start transmitting clean-coded signals. Further, any changeover to clean coding will not happen overnight, and the broadcasters have an immense stock of conventionally coded programmes on tape; so conventionally coded signals must not produce inferior results on new receivers with clean decoders. This requirement for compatibility rules out any radical change to the signal specification.

All clean PAL systems attempt to improve on the compromise between resolution and crosseffects which is implicit in a band-shared system. For example, it would be possible to eliminate crosseffects by low pass filtering the luminance signal to restrict its bandwidth to 3.5 MHz, reserving the upper part of the available band exclusively for chrominance. But cutting off all luminance above 3.5 MHz would make pictures unacceptably soft. However, there are other aspects where there is more room for compromise: for instance the vertical chrominance bandwidth is much greater than the horizontal bandwidth. Some clean PAL systems in effect exchange vertical chrominance resolution for luminance resolution while still reducing crosseffects. No clean PAL system gives something for nothing: the most that can be hoped for is the reduction or elimination of objectionable effects like crosscolour in exchange for the introduction of less visible effects such as reduced vertical chrominance resolution.

Luminance notch filters are sometimes used in PAL coders to remove luminance components around the colour subcarrier frequency, which would otherwise cause crosscolour. But the notch characteristic that was found to be optimum[1] still leaves some crosscolour and has caused complaints that it makes pictures appear soft. All conventional PAL decoders also contain a notch filter to attenuate colour subcarrier (crossluminance) in plain coloured areas[2]. With such a decoder, crossluminance appears only as subcarrier dots on vertical coloured edges in the picture, where the sidebands of the modulated chrominance signal lie outside the stopband of the filter. Because notch filters do not completely remove crosseffects and reduce luminance resolution a better solution is needed.

Apart from simple notch filters, several other methods have been proposed. One uses comb filters to split the signal spectrum at the coder into separate bands for luminance and chrominance. Matched filters at the decoder can then separate chrominance and luminance again[3]. The comb filters use four lines of delay and give poor vertical chrominance resolution.

Another approach is to add to the signal at the coder a signal which is in antiphase to the luminance components that would cause crosscolour. At the matched decoder these antiphase components cancel out the crosscolour. One method based on this approach has already been put forward by Auty, Read and Roe[4]. This Report introduces another method using a similar approach based on the Weston Y_2, $(U \pm V)$ digital transmission system[5,6]. Both these methods also reduce crossluminance. Subjective tests have shown that the Weston scheme gives a worthwhile improvement to colour pictures; but it may not be the optimum clean PAL system and should not be taken as definitive for the future.

2. The Weston clean PAL coder and decoder.

2.1 The Weston Y_2, $(U \pm V)$ transmission system

The Weston clean PAL coding scheme has been developed from the digital Y_2, $(U \pm V)$ transmission scheme. A full description of this has already been given,[5,6] but for completeness a short description will be given here.

The Y_2, $(U \pm V)$ transmission system shown diagramatically in Fig. 1 was proposed as a possible bridge between countries using PAL in the studios and for broadcasting, and countries using *YUV* in the studios and then coding to SECAM for broadcasting. A luminance signal, Y_2, sampled at twice PAL subcarrier frequency ($2f_{sc}$) and a chrominance signal $(U \pm V)$ sampled at f_{sc}, consisting of $(U + V)$ and (U/V) on alternate lines, would be transmitted on the international network. These signals can be derived from *YUV* by a prefilter and chrominance combiner, or from PAL by a PAL splitter. The Y_2, $(U \pm V)$ signals can be converted to *YUV* by a postfilter and chrominance separator, or to PAL by a PAL assembler.

The Y_2, $(U \pm V)$ system has two important properties. The PAL→PAL path (route 1 in Fig. 1) is lossless: all the information which is lost in the luminance path is carried in the chrominance path, and vice versa. This means that the Y_2, $(U \pm V)$→ PAL and PAL→ Y_2,$(U \pm V)$ processes can be repeatedly cascaded without impairments building up. And the *YUV* → *YUV* path (route 4 in Fig. 1) gives no luminance – chrominance cross-effects, because the luminance and chrominance signals are never combined. This route is not lossless, however: the output Y signal contains aliasing from the $2f_{sc}$ sampling process, and there is U/V crosstalk which shows itself as flickering effects where the chrominance signals change from one line to the next.

2.2 The Weston Y_2, $(U \pm V)$ system as a PAL coder and decoder.

The path from *YUV* to PAL through the Y_2, $(U \pm V)$ system (route 2 in Fig. 1) is equivalent to a form of PAL coding; and the path from PAL to

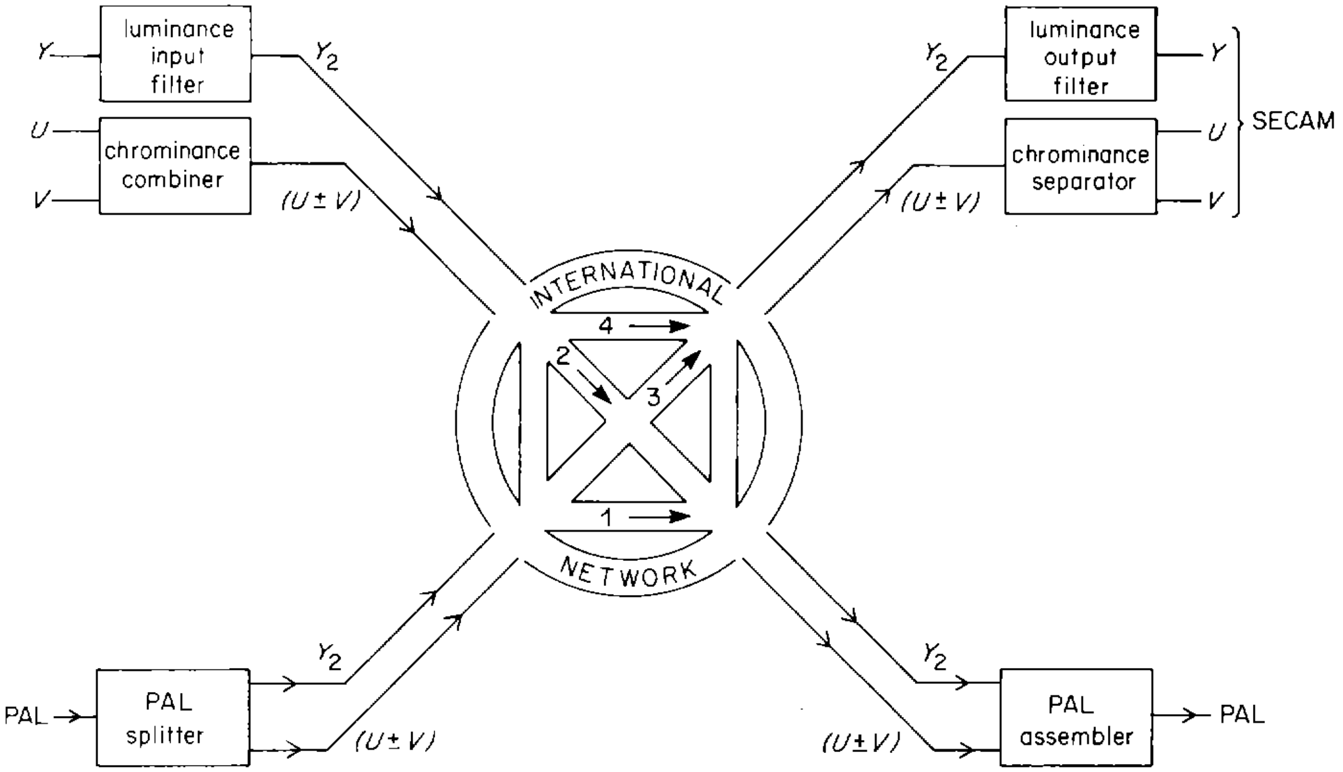

Fig. 1 - Proposed Y_2, $(U \pm V)$ system for international exchange

YUV through the system (route 3 in Fig. 1) is equivalent to a form of PAL decoding. These two routes have become known as Weston PAL coding and Weston PAL decoding respectively.

It has already been noted[6] that Weston PAL coding generates no coarse crosscolour (caused by luminance components close to the U and V carriers), whereas Weston PAL decoding generates no fine crosscolour (caused by luminance components at multiples of line frequency). It has now been realised* that Weston coding followed by Weston decoding has no crosseffects at all, and is thus a clean PAL system. This is because the $YUV \rightarrow Y_2, (U \pm V) \rightarrow \mathrm{PAL} \rightarrow Y_2, (U \pm V) \rightarrow YUV$ process is equivalent to the simple $YUV \rightarrow Y_2, (U \pm V) \rightarrow YUV$ process. This follows from the fact that the $\mathrm{PAL} \rightarrow Y_2, (U \pm V) \rightarrow \mathrm{PAL}$ process is lossless; hence, the $Y_2, (U \pm V) \rightarrow \mathrm{PAL} \rightarrow Y_2, (U \pm V)$ process is also lossless. Although Weston coding followed by Weston decoding has no crosseffects, there remain the luminance aliasing and U/V crosstalk described above from the $YUV \rightarrow Y_2, (U \pm V) \rightarrow YUV$ process. However, these self-effects are not cumulative because the filters in the $YUV \rightarrow Y_2, (U \pm V) \rightarrow YUV$ path are cascadable.

Strictly speaking, this is true of the system described in Refs. 5 and 6 only if the bandpass filters used in the PAL splitter and PAL assembler are ideal; that is, their response must be unity in band and zero out of band, with an infinite rate of cut. If the bandpass filters are not ideal, there will be loss in the $\mathrm{PAL} \rightarrow Y_2, (U \pm V) \rightarrow \mathrm{PAL}$ path and crosseffects will appear in the $YUV \rightarrow \mathrm{PAL} \rightarrow YUV$ path in the filter transition region at the band edges. However, there may be forms of PAL splitter and assembler other than those described in Refs. 5 and 6 which are more practicable. The freedom from crosseffects depends only on the filters in the $\mathrm{PAL} \rightarrow Y_2, (U \pm V) \rightarrow \mathrm{PAL}$ path, not on those in the $YUV \rightarrow Y_2, (U \pm V) \rightarrow YUV$ path which can be chosen to minimise the unwanted effects in this path – the luminance aliasing and U/V crosstalk.

2.3 A practical rearrangement of the Weston clean decoder

The Weston transmission system was conceived as a digital system and was implemented digitally using subcarrier-locked sampling frequencies. A block diagram of the $\mathrm{PAL} \rightarrow Y_2, (U \pm V) \rightarrow YUV$ process (Weston clean decoding) is shown in Fig. 2. The decoder achieved separation of luminance from the PAL signal by averaging the signals in the

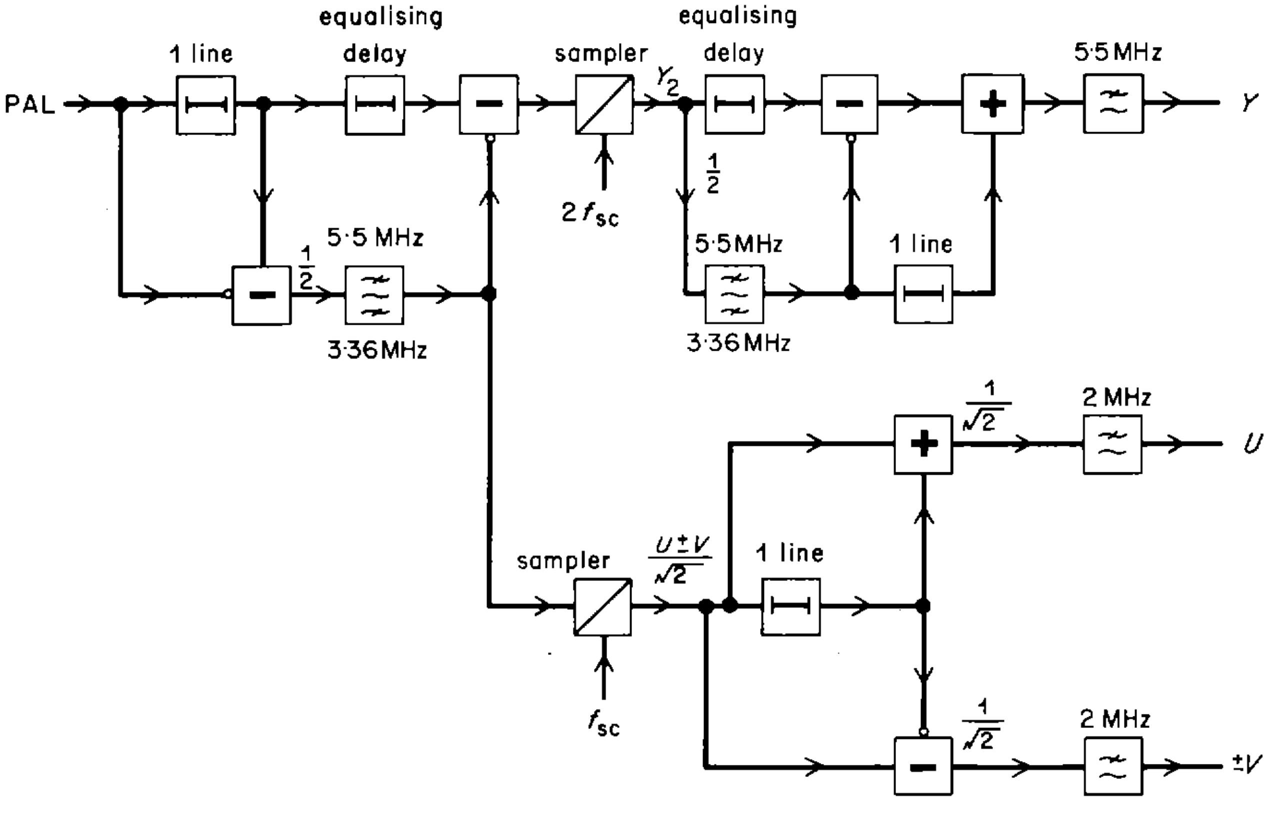

Fig. 2 - Weston clean PAL decoding – the PAL to YUV process via $Y_2, (U \pm V)$.

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* By J.O. Drewery.

chrominance region across a line delay, thus bringing the U and V components into phase, and then sampling the resulting signal (at $2f_{sc}$) at the zero-crossings of the chrominance components. At the same time the chrominance was separated by subtracting across a line delay to eliminate line-repetitive luminance components, sampling at f_{sc} (equivalent to demodulation), and splitting U from V.

This form of digital decoder is not suitable for use in television receivers, where a simple analogue circuit is needed. Nor could it be used with line-locked digital signals which may be used in digital studios in the future. So a practical rearrangement of the decoder is needed which eliminates the need for $2f_{sc}$ sampling. Such a decoder could be realised in analogue form or digitally at any convenient sampling frequency.

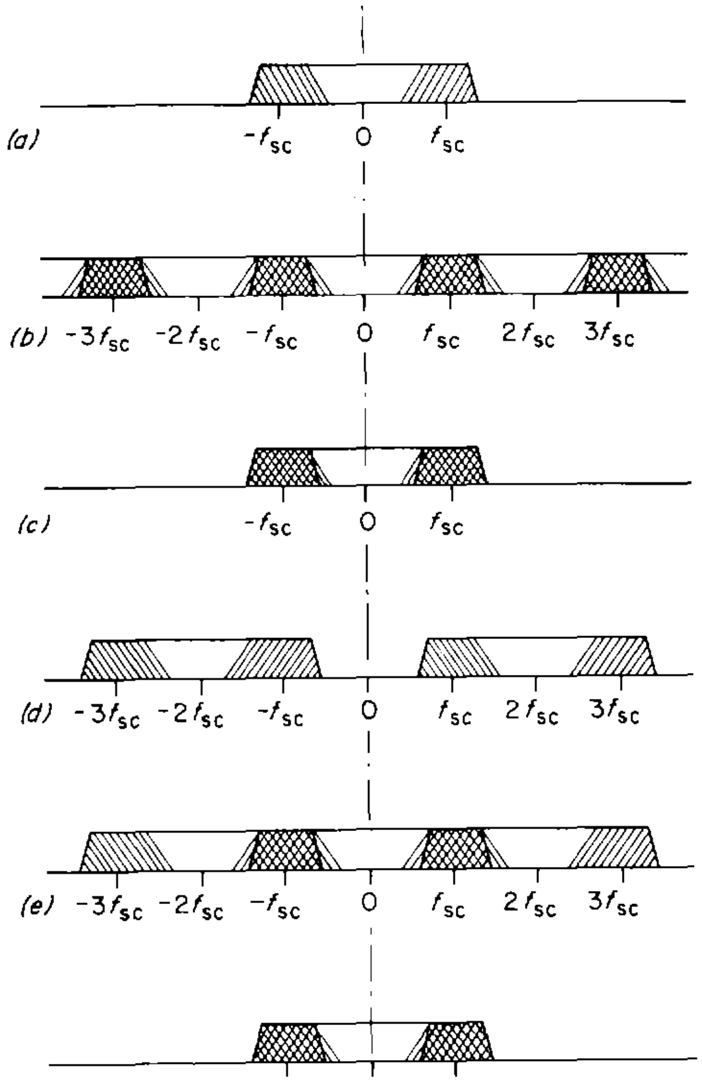

Fig. 3 - $2f_{sc}$ sampling and PAL modification

(a) Baseband signal spectrum
(b) Spectrum of signal sampled at $2f_{sc}$
(c) Lowpass filtered version of (b)
(d) Spectrum of signal multiplied by $2f_{sc}$
(e) (d) and (a) added
(f) Lowpass filtered version of (e)

The effect of $2f_{sc}$ sampling is shown spectrally in Fig. 3. The figure also shows that the same effect can be achieved over the video band by adding to the original baseband signal the same signal multiplied by a sinewave at $2f_{sc}$. So the effect of $2f_{sc}$ sampling over the video band can be duplicated by analogue multiplication, addition and lowpass filtering. Further, provided the input to the multiplier is suitably bandpass filtered, the same effect over the chrominance band can also be achieved digitally at any convenient sampling frequency near $3f_{sc}$[7]. The sampling at f_{sc} in the chrominance path is likewise equivalent to demodulation, and the chrominance postfilter in Fig. 2, suitably transformed, may precede a quadrature demodulation process, consistent with a $2f_{sc}$ multiplication operation.

This operation of multiplying the PAL signal by a $2f_{sc}$ sinewave is known as PAL modification. It was originally devised by Bruch for use in equipment for correcting differential phase and gain. In practical terms, the PAL modifier reverses the sense of the V-axis switch in the modulated chrominance signal; depending on the phase of the $2f_{sc}$ sinewave it can also introduce a phase change in both U and V signals. It also introduces a luminance alias component centred on $2f_{sc}$ in the same way as a $2f_{sc}$ sampling operation.

Fig. 4 shows a practical form of Weston clean decoder. It is derived from the circuit of Fig. 2 by substituting a PAL modifier for the sampling process, and rearranging, as described above. The equivalence of the two circuits is demonstrated in Appendix 1.

To see how this form of decoder works, first consider a signal representing a plain coloured area. The signals at points a and b are two lines apart so their chrominance components are 180° out of phase. Adding them therefore produces no chrominance at point c. All the chrominance information at point d has thus come from the centre tap of the two-line delay. Subtracting across the two-line delay causes the chrominance signals to reinforce each other, producing a signal at point e which, in plain areas, is the same as that at d except that it is 90° out of phase and its V-axis switch is reversed. The phase is corrected

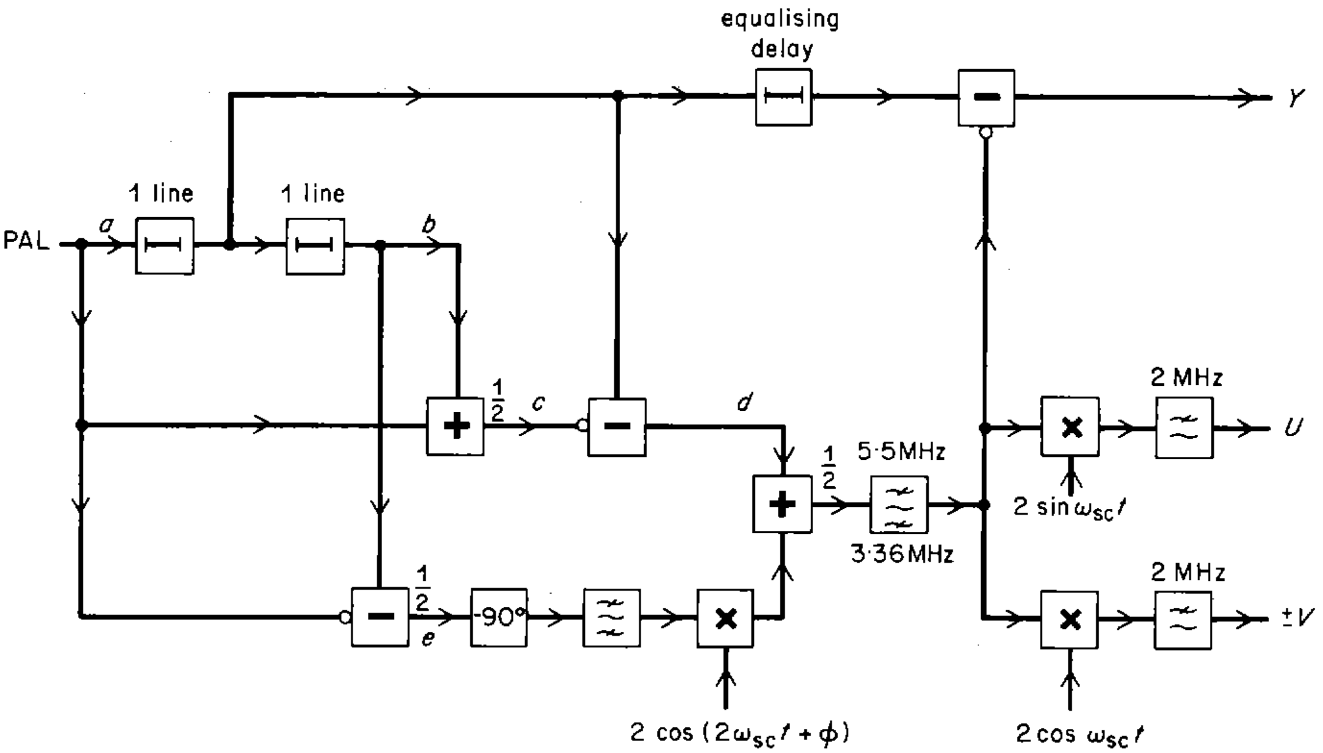

Fig. 4 - Rearrangement of Weston clean decoder.

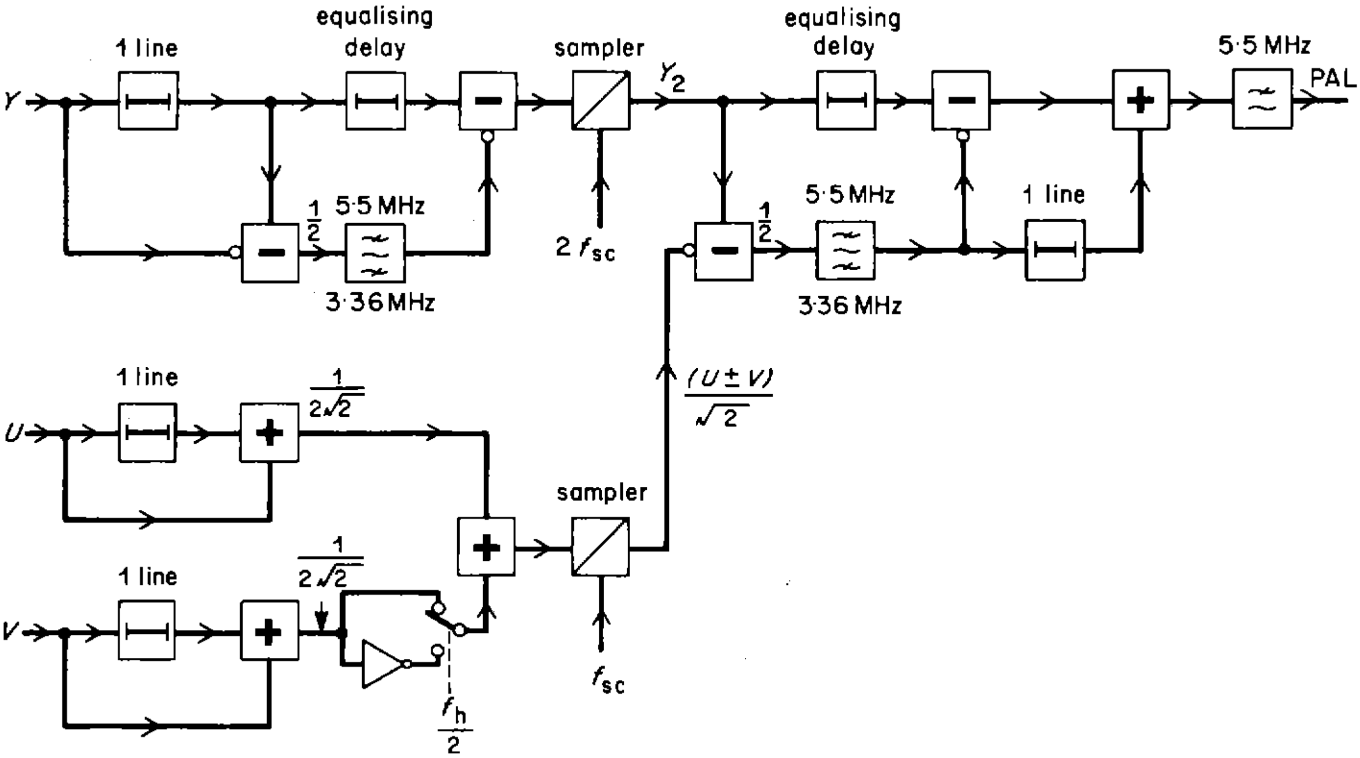

Fig. 5 - Weston clean PAL coding – the YUV to PAL process via Y_2, (U ± V).

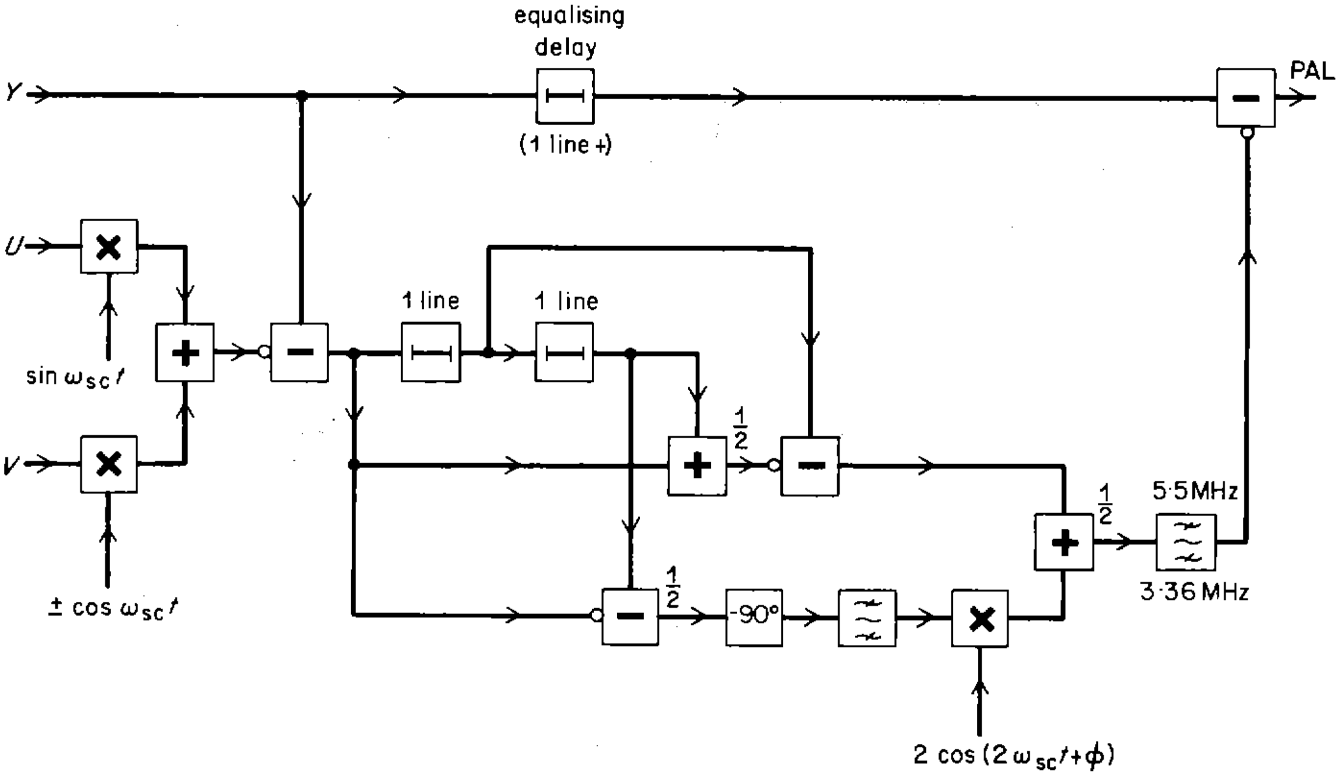

Fig. 6 - Rearrangement of the Weston clean coder.

by the 90° phase shift and the V-axis switch is put right by the modifier, so that the two signals can be averaged, and then demodulated in the usual way. In practice the 90° phase shift would be carried out by the modifier. The separated chrominance signal is subtracted from the coded signal to give luminance free of subcarrier patterning.

Now consider the effect of the decoder on signals representing line-repetitive fine luminance detail, such as test card resolution bars. In a conventional decoder such signals would produce fine crosscolour and would be attenuated by the notch filter in the luminance channel. In the Weston decoder, averaging over two lines of delay gives signals at *c* which are identical to the input and are cancelled at *d* by subtracting from the input signal. Subtracting across two lines of delay also cancels line-repetitive signals, so there is no signal at point *e*. Thus line-repetitive luminance signals produce no signal in the chrominance path and hence no crosscolour. Further, because there is no signal through the PAL modifier, no alias is added to the luminance signal.

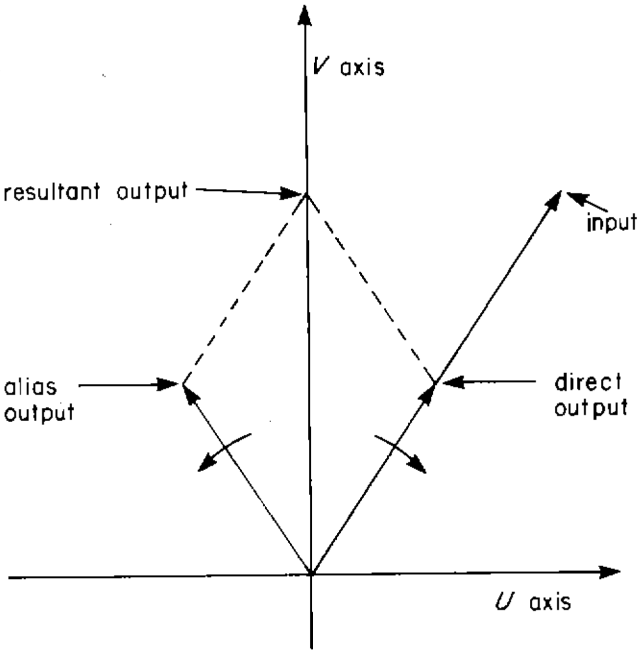

Fig. 7 - Vector diagram — removal of crosscolour.

2.4 A similar rearrangement of the Weston clean coder

Fig. 5 shows a block diagram of the $YUV \rightarrow Y_2, (U \pm V) \rightarrow$ PAL process (Weston clean coding).

This can be rearranged into the form shown in Fig. 6, which is suitable for implementation either in analogue form or digitally at any convenient sampling frequency close to $3f_{sc}$. It can be seen that the coder and decoder circuits are very similar; this similarity between coder and decoder filters is dealt with more fully in Appendix 2.

The reason why a modifier is useful in a PAL coder is that it adds a luminance alias component which cancels out coarse crosscolour in the PAL decoder. Coarse crosscolour in the decoder U output is generated by luminance components which are a quarter of line frequency below multiples of line frequency. Fig. 7 shows one such component as a vector in the U/V phase diagram, rotating at a rate equal to the difference between input and subcarrier frequencies. PAL modification produces a counter rotating alias component. The modifier is arranged so that the resultant output always lies parallel to the V-axis and so is ignored by the U demodulator in the decoder. For inputs a quarter of line frequency above multiples of line frequency which would give coarse V crosscolour, the comb filter inverts the modifier input so that in this case the resultant output lies parallel to the U axis and is therefore ignored by the V demodulator. Since both original and alias signals at 6 dB down, the potential for causing fine crosscolour is unaffected.

The coder filter treats plain-area subcarrier and line-repetitive luminance in the same way as described for the decoder: plain area subcarrier is identical to that produced by a simple coder, and line-repetitive luminance does not go through the modifier path, and so produces no alias component.

2.5 Spectra of Weston clean coded and decoded signals

The circuits described in Sections 2.3 and 2.4 may be analysed to derive the spectra of the coded and decoded signals. Since the coder and decoder filters contain line delays, the spectra will repeat at multiples of line frequency f_L. So all the spectra need be represented only in the interval from one multiple of line frequency to the next, within the region defined by the chrominance bandpass filters.

Fig. 8 shows the spectrum of the coded signal. It is divided into four components: original luminance (Y), luminance alias (Y'), and the two chrominance components (U and V). There is a zero of both Y and Y' at half-line offsets,

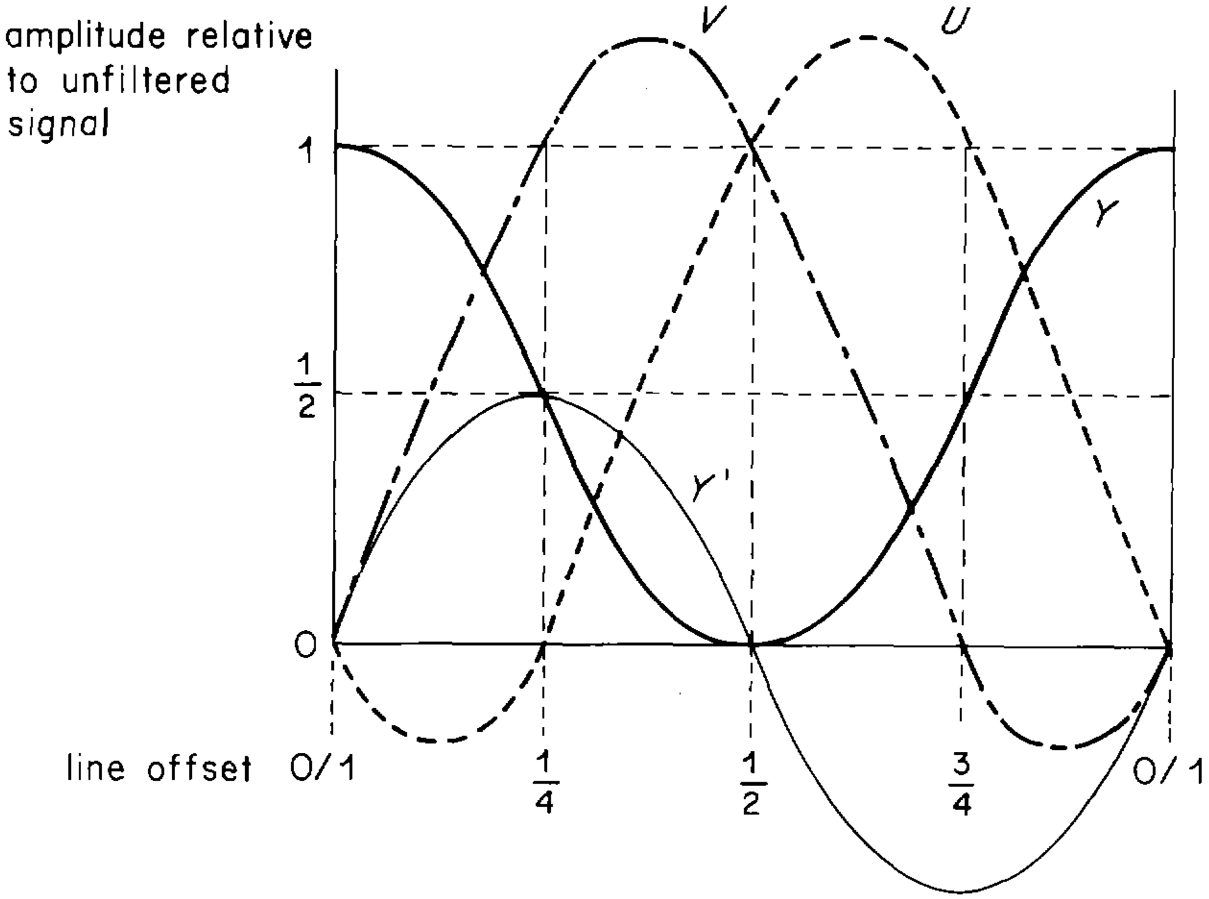

Fig. 8 - Spectrum of the clean coded signal

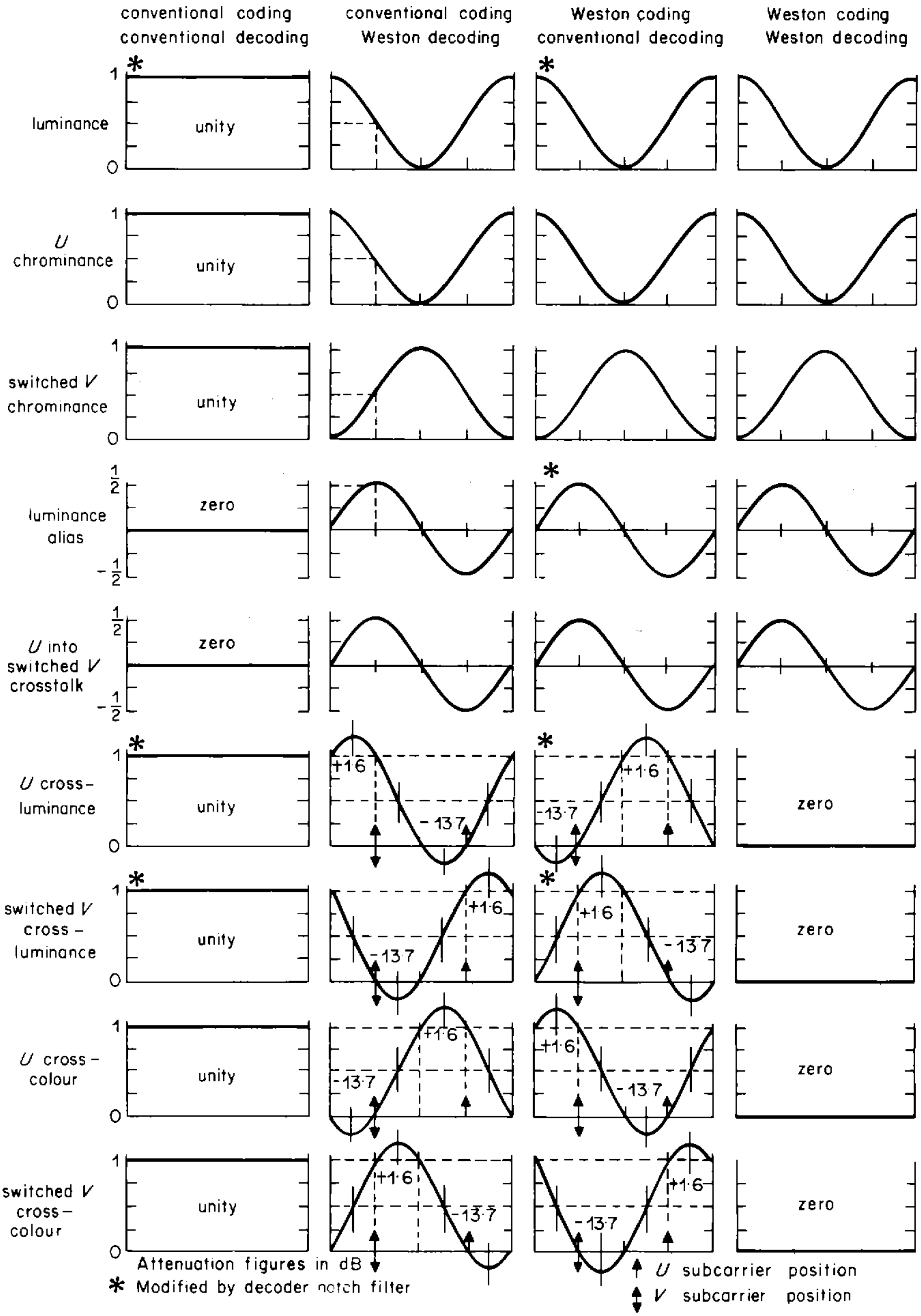

Fig. 9 - Spectra of decoded signals.

indicating that some fine diagonal detail has been removed. At the quarter and three-quarter line offsets (the chrominance carrier positions) both the original luminance signal and the luminance alias are 6 dB down relative to the unfiltered signal. The chrominance signals *U* and *V* are asymmetrical about their carriers, the signals being biased towards half-line offsets. The chrominance signals also peak to 1.6 dB above the unfiltered level.

When the signals are decoded, there are ten signal spectra to be taken into account: the wanted luminance and two wanted chrominance signals, the luminance alias signal, two *U/V* crosstalk signals (one for *U* into *V* and one for *V* into *U*), two crosscolour characteristics (for *Y* into *U* and *Y* into *V*) and two crossluminance characteristics (one for *U* into *Y* and one for *V* into *Y*).

There are also the four combinations of conventional coder, Weston clean coder, conventional decoder and Weston clean decoder to be considered. Fig. 9 shows these spectra for all four cases. In the two cases using conventional decoding, the decoder considered is a simple one without a delay line; in practice in these cases the characteristics for luminance and crossluminance would be affected by the decoder's luminance notch filter, and the PAL delay line would introduce a cosine term into the chrominance characteristics.

In all cases involving Weston clean coding or decoding, the wanted luminance signal is zero at half line offsets. The luminance alias is also zero at half line offsets. The result is that some fine diagonal detail in the picture is completely removed. The chrominance signals are also zero at half line offsets, but in this case the loss applies at all frequencies, not just to fine detail. So the chrominance signals are extinguished at a vertical frequency of 156 cycles per picture height. This also applies, of course, to signals from a conventional delay-line decoder. However, when a Weston clean coder and decoder are cascaded, the loss of vertical chrominance resolution is not

TABLE 1

Coding	Conventional	Conventional	Clean	Clean
Decoding	Conventional	Clean	Conventional	Clean
Y resolution	Notch	Diagonal loss	Notch + diagonal loss(2)	Diagonal loss(2)
C vertical resolution	Excellent(1)	Good(2)	Fair(3)	Good(2)
Crosscolour	Coarse and fine	Only fine removed	Only coarse (vertical) removed	None
Crossluminance	Only on vertical *C* edges	Only on horizontal *C* edges	Only on vertical *C* edges	None
Y aliasing(4)	None	Some(5)	A little(6)	Some
U/V crosstalk(7)	None	Some(8)	A little(9)	Some

Notes

(N.B. 78 c/ph is equivalent to 1.84 MHz)

(1) −3 dB at 78 c/ph and extinction at 156 c/ph caused by averaging across one line of delay.

(2) Twice loss of (1)

(3) Three times loss of (1)

(4) −6 dB maximum at 78 c/ph.

(5) Concealed by coarse crosscolour.

(6) Because largely removed by decoder notch.

(7) On horizontal chrominance edges.

(8) But subjectively improved by cross-luminance.

(9) Because mitigated by action of PAL delay line.

cumulative as mentioned in Section 2.2

3. Advantages and disadvantages of clean coding*

3.1 Properties of clean coding and decoding

Table 1 shows the properties of the four possible combinations of conventional coding and decoding and clean coding and decoding. From this table can be assessed the advantages and disadvantages of the scheme and also its compatibility with conventional coders and decoders. This section discusses the subjective effects of the properties listed in the table.

Clean decoding gives a subjective improvement of luminance resolution. This is because the notch filter in a conventional decoder attenuates all signals close to the colour subcarrier frequency, whereas the clean decoder cancels out subcarrier by combining signals from adjacent lines without using a notch filter. It thus leaves untouched signals representing fine verticals in the picture (which occur frequently), attenuating only fine diagonals (which are much less frequent). Furthermore, the loss from the notch filter is cumulative with the loss from any crosscolour-reducing notch filter in a conventional coder, whereas the diagonal losses from clean coding and decoding are not cumulative.

Both clean coding and decoding reduce vertical chrominance resolution. But conventionally coded signals have a much greater vertical chrominance bandwidth than horizontal, whereas the eye's response is isotropic; so the vertical loss from clean coding or decoding is not noticed. Again, the losses from clean coding followed by clean decoding are not cumulative; but the loss from clean coding is cumulative with that from conventional delay-line decoding.

Clean coding alone removes coarse crosscolour and clean decoding alone removes fine crosscolour. Most observers find coarse crosscolour more annoying so that the introduction of clean coding alone would bring a worthwhile improvement to viewers with conventional decoders in their receivers.

The luminance alias introduced by clean coding or decoding is noticeable only when both clean coding and clean decoding are used. The alias can easily be seen since it moves relative to the signal which causes it. In areas of fine detail it beats with the wanted luminance information to give a low frequency monochrome pattern running through the wanted information. The degree of annoyance caused by this pattern depends on the sharpness of the display and,because of the gamma of the tube, on the amplitude and mean level of the signal causing it. More work will be needed to see whether it is an acceptable impairment.

The *U/V* crosstalk resulting from clean coding and decoding causes a 12½ Hz flicker on horizontal chrominance edges. This flicker can easily be seen on test signals such as horizontal colour bars, but is not generally noticed on real pictures. It is of the same kind as the 'chrominance hop' seen with SECAM, but with clean coding and decoding its visibility is much reduced by the filters which reduce vertical chrominance resolution.

It should be noted that the impairments from clean coding and decoding – the luminance aliasing, reduced vertical chrominance resolution and the *U/V* crosstalk – are exactly the same as those caused by sub-Nyquist sampling at $2f_{sc}$ of conventionally coded PAL signals. This still applies however the clean coded signals are produced, even when no sampling is involved. But with $2f_{sc}$ sampled PAL, a conventional delay-line decoder with a luminance notch filter is generally used, which reduces the visibility of these effects. The impairments could be reduced by the use of more complicated filters, combining signals from more field lines or from more than one field. These methods have not yet been investigated, so it is difficult to say how objectionable would be the impairment in vertical and temporal resolution they might cause.

The improvements from clean coding and decoding can be seen in Figs. 10 and 11. These pictures show BBC Test Card F; they were taken from a monochrome monitor fed with the green signal from the PAL decoder. Fig. 10 shows the green signal from a conventional decoder (with a notch filter) fed by a conventional coder (without a notch filter). Fine crosscolour can be seen as a pattern on the resolution gratings, and coarse crosscolour on the diagonal bars at the corners. Cross luminance can be seen on the edges of the coloured castellations at the top of the picture. The notch filter in the decoder has attenuated the 4.5 MHz resolution gratings and has caused ringing following transitions. (Decoder notch filters – even in professional decoders – are rarely group-delay corrected).

Fig. 11 shows the green signal from a clean

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* The term 'clean PAL' has been used for any improved PAL coding and decoding scheme which reduces or eliminates crosseffects. For the remainder of this report it is used to refer specifically to Weston clean PAL.

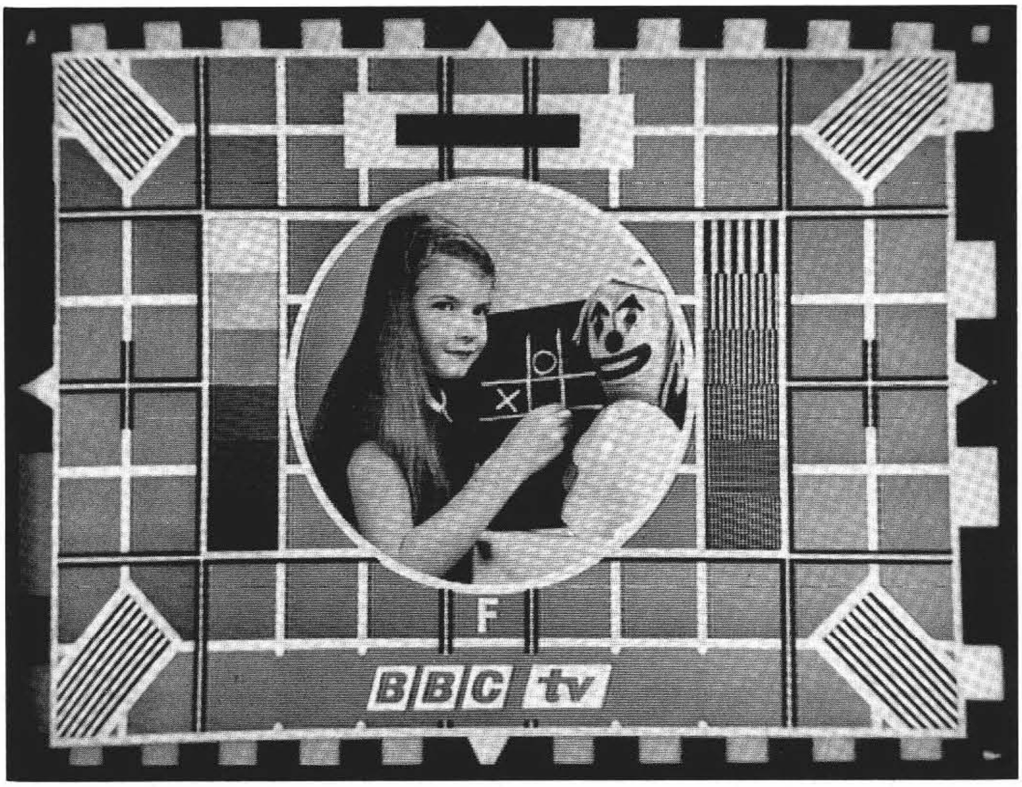


Fig. 10 - Test card — conventional coding and decoding

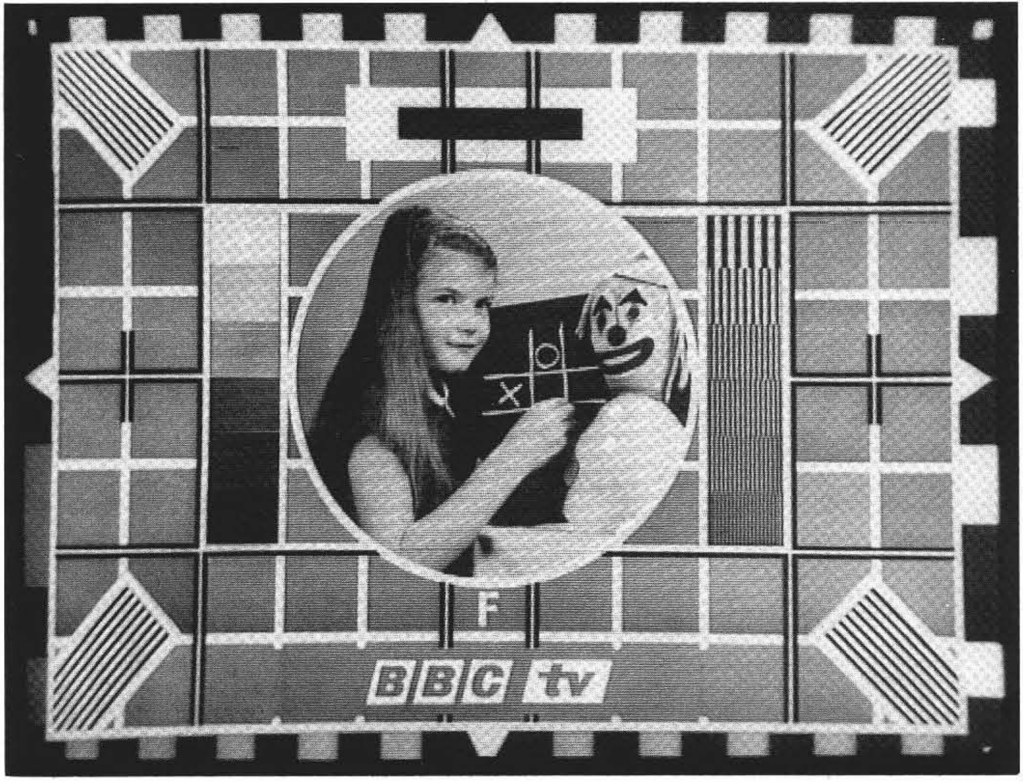


Fig. 11 - Test card — clean coding and decoding

coder and decoder. The picture is now free of crosscolour and crossluminance and has full resolution to 5.5 MHz of the verticals in the resolution bars.

3.2 Compatibility of the clean coding scheme.

Table 1 shows that clean coding followed by conventional decoding and conventional coding followed by clean decoding give good pictures; the requirement for compatibility is thus satisfied.

But although the clean coding scheme is compatible with conventional coders and decoders, it demands better phase performance from both the transmission system and the receiver if its potential for complete freedom from coarse crosscolour is to be realised. This is because the scheme relies on an antiphase alias component to cancel out coarse crosscolour. If the decoder phase is incorrect, or if there is phase distortion in the transmission path, the coarse crosscolour will not cancel completely. However it might be possible to allow for more accurate setting of decoder phase by incorporating in the test card commonly used for setting up receivers a signal which would generate coarse crosscolour; the decoder phase could then be set for minimum crosscolour. It should be noted that in a conventional PAL coding and decoding scheme, incorrect setting of decoder phase also increases crosscolour. This happens because the viewer increases the colour saturation to offset the desaturation caused by the incorrect decoding phase.

Another problem arises with a bit-rate-reducing system which may be used for the digital transmission of television signals in the future. This system uses sub-Nyquist sampling at twice colour subcarrier frequency ($2f_{sc}$). It will be remembered that the Weston Y_2, $(U \pm V)$ transmission system, from which clean PAL was developed, used twice subcarrier frequency sampling for its luminance signal. It might therefore be thought that there would be no problem if the two systems were used in tandem. However, they exploit the redundancy of the PAL system in different ways. When a clean coded PAL signal is passed through the $2f_{sc}$ -sampled sub-Nyquist process, coarse crosscolour caused by luminance components close to the colour subcarrier positions is brought back. Furthermore, the losses of diagonal luminance resolution and of vertical chrominance resolution caused by the two systems are

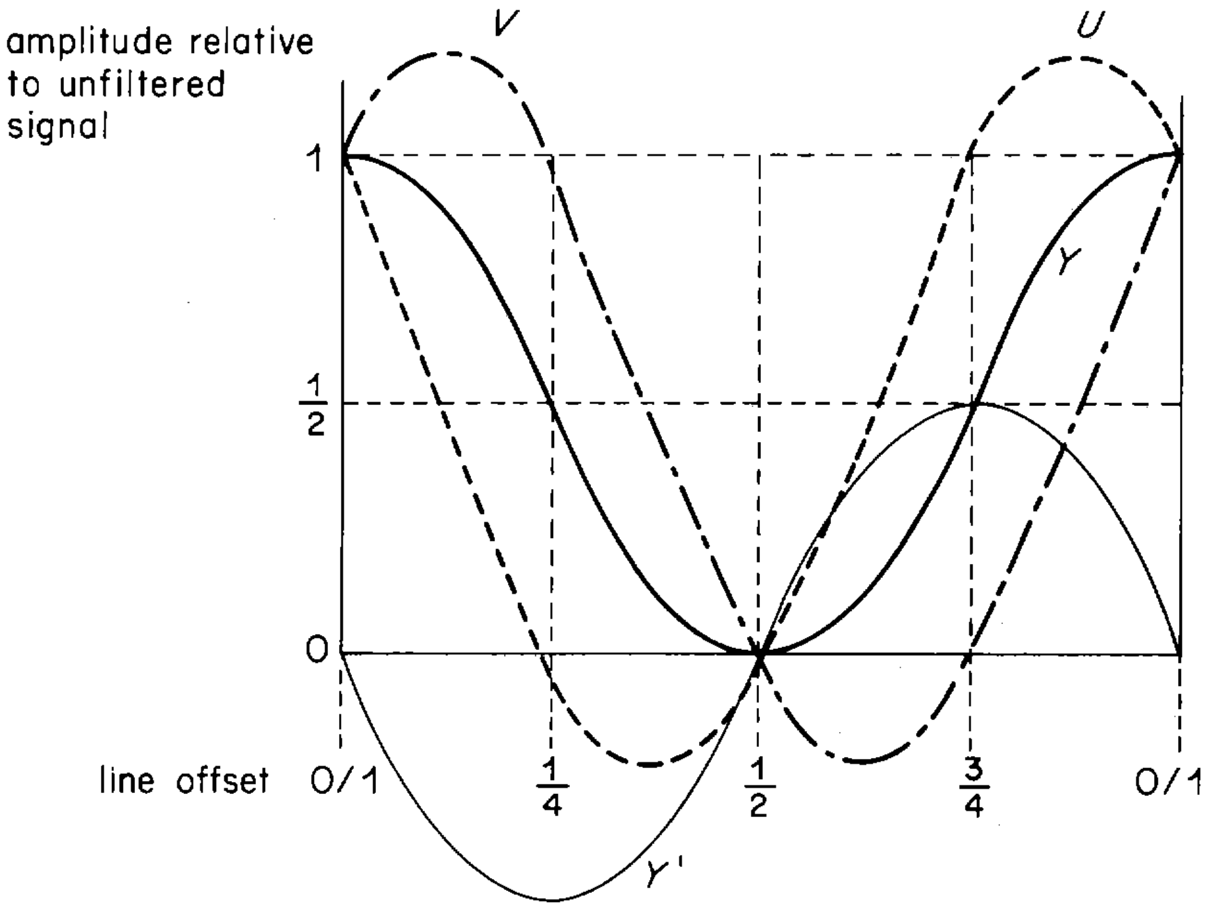


Fig. 12 - Spectrum of sub-Nyquist sampled PAL.

cumulative; on the other hand the reduced luminance diagonal resolution makes the aliasing less visible, and the loss of vertical chrominance resolution makes the *U/V* crosstalk less visible.

This significant difference in system properties can be explained spectrally, by comparing Fig. 8, the spectrum of a clean coded PAL signal, with Fig. 12 which shows the spectrum of a $2f_{sc}$ sampled conventionally coded PAL signal. The luminance alias signals of the two cases are opposite in phase; this means that $2f_{sc}$ sampling of the clean coded signal reduces the alias which the clean system uses to cancel coarse crosscolour. The chrominance signals are carried in both cases by an asymmetrical vertical sideband system; but whereas in clean coding the signals are biased towards half-line offsets, in the $2f_{sc}$ system they are biased towards line offsets.

The use of field or picture delays in the comb filters of the sub-Nyquist $2f_{sc}$ system[8] offers no solution to this difficulty. A $2f_{sc}$ system using picture delays is transparent to conventional PAL coding of stationary pictures; but Weston coding introduces a *moving* alias component even on *stationary* pictures. This moving alias component, on which the cancellation of coarse crosscolour depends, would be attenuated by a sub-Nyquist sampling system using picture-delay comb filters.

3.3 Some hardware implications

The block diagrams of the clean coder and decoder (Figs. 4 and 6) show that in both cases the main term of the output, containing the whole of the low-frequency part of the signal, is delayed by one line; that is, both coder and decoder have a constant group delay of one line period. So both coder and decoder need one wideband line delay. The second line delay in the decoder and two of the line delays in the coder handle only signals which are to be bandpass filtered, so in the analogue form of the coder and decoder they can be narrowband delays like those used in conventional delay-line decoders. It is possible that the wideband delay might use a CCD (Charge-Coupled Device) analogue shift register; a CCD line delay might in future be cheaper than a glass delay line, and would certainly be more accurate – glass delay lines are notoriously prone to cause distortion, and to add echoes and noise.

The fact that the coder has a delay of one line will lead to timing problems in studios (e.g. lining up coded signals with the RGB signals needed for Colour Separation Overlay (C.S.O.)); but with some retiming of blanking and colour separation overlay signals the difficulties can probably be overcome.

4. Subjective tests

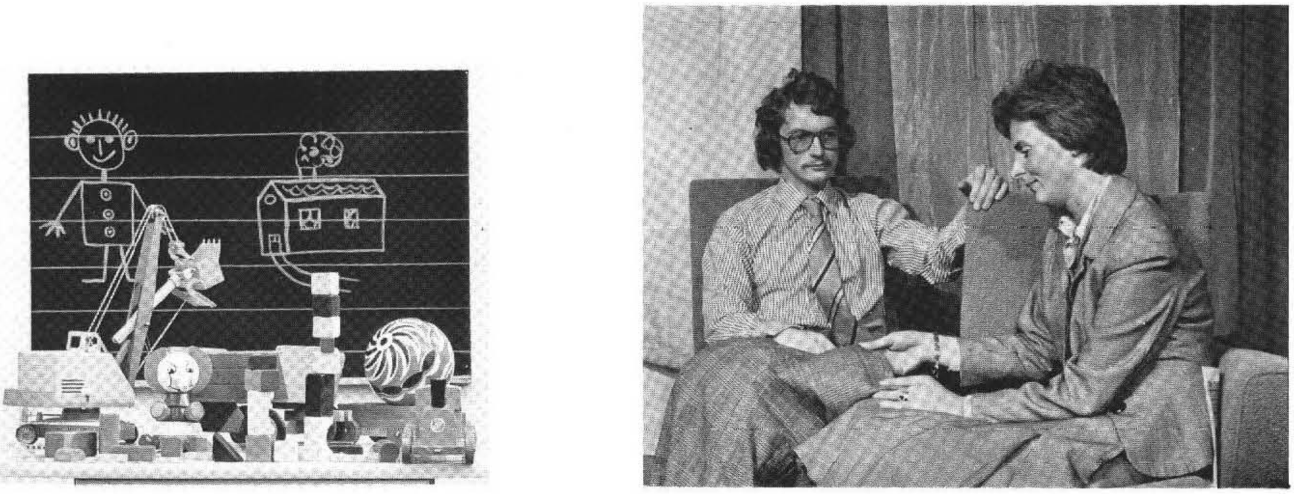
4.1 General

Subjective tests using the Y_2, $(U \pm V)$ equipment as a transmission system have already been reported[5,6]. Some of these tests included assessments of Weston PAL coding and Weston PAL decoding conditions. Since these tests were carried out three more series of tests have been performed on different aspects of the system as a clean PAL coding scheme. These three series of tests all used the same pictures and test procedure, so their results will all be presented together.

The first of these three series of tests assessed combinations of conventional or clean coding with conventional or clean decoding, using colour pictures only. Only one set of Y_2, $(U \pm V)$ equipment has been built; this can be used as a clean PAL coder or as a clean PAL decoder, but not as both at once. So the only way tests could be carried out on clean coding followed by clean decoding was to record the coded signals in analogue form on videotape, and then to play them back through the equipment used as a decoder. This introduced uncontrolled impairments due to the videotape process.

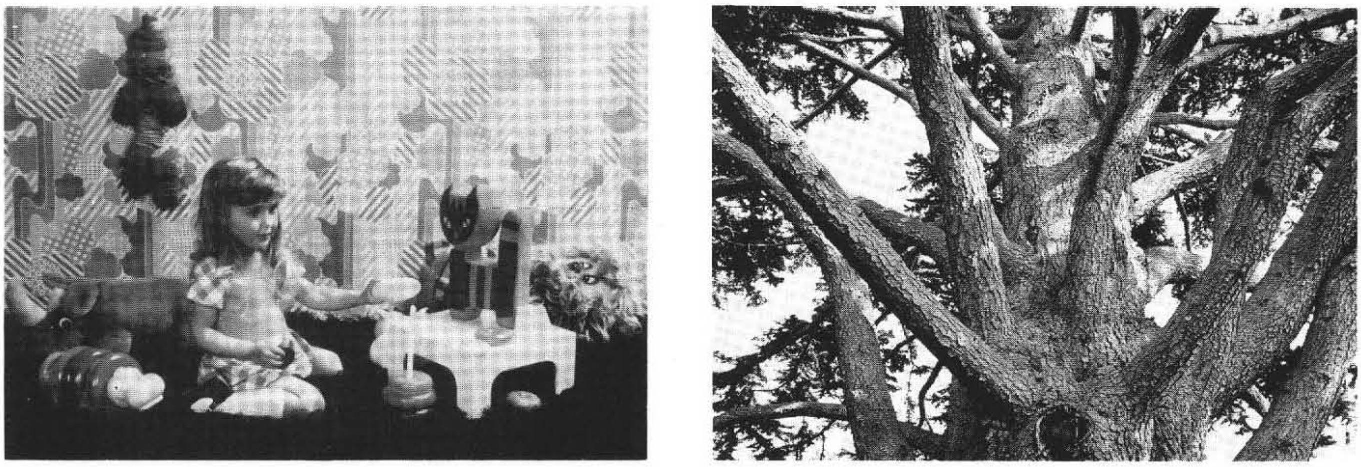
The second series of tests compared only different coders, using a conventional delay-line decoder in each case. Besides conventional and clean coders, a coder with a luminance notch filter was tested, as well as two forms of coder based on the proposals of Auty, Read and Roe[4]. The third series of tests compared conventional, notched and clean coders with and without a $2f_{sc}$ sub-Nyquist sampling process applied to the coded signal, again using a conventional delay-line decoder in all cases.

Both the second and the third series of tests used colour and monochrome pictures. For the purposes of this report, the results for conventional, notched and clean coding alone have been extracted from the results of these two series and corresponding results combined to give bigger samples; statistical analysis showed that there was no systematic difference between the results extracted from the two different series of tests.



(a) Blackboard

(b) Couple



(c) Girl with toys

(d) Tree

Fig. 13 - Slides used in subjective tests.

4.2 Test pictures

The signal source for all the tests was a high-quality flying-spot slide scanner with logarithmic masking and both horizontal and vertical aperture correction. Pictures were displayed on a 22″ shadowmask colour monitor or a 20″ monochrome monitor.

Four slides were used in the tests; three were EBU slides, "Blackboard", "Tree", and "Girl with Toys", and the fourth was a specially-shot slide of two people seated in a studio setting, wearing striped and checked clothes ("Couple"). Monochrome versions of these slides are shown in Fig. 13. The slides "Blackboard"and "Girl with Toys" are more critical for chrominance effects – chrominance bandwidth, *U/V* crosstalk and cross-luminance – but contain little fine detail to cause crosscolour. The other two slides, "Couple" and "Tree" contain much fine detail and so are more critical for luminance resolution and crosscolour. The "Couple" slide also gives interlace flicker, so the pictures are marked down even without other impairments.

4.3 Test procedure

Ten experienced observers, in two groups of five, took part in each of the three series of tests. Each group was subjected to two sessions of tests in colour and, in the second and third series of tests, to two sessions in monochrome. They were seated between four and six times picture height from the monitor. The peak brightness of the monitor was set to 70 cd/m^2 and its cutoff was set using the standard lineup waveform (PLUGE). The background illumination in the test room was low and consisted mainly of diffuse daylight.

TABLE 2
Results of first series of subjective tests
(averages of 10 observers; figures in parentheses are standard deviation)

Coder	Conventional	Conventional	Clean	Clean
Decoder Slide	Conventional	Clean	Conventional	Clean
Blackboard	3.90 (.60)	4.13 (.58)	4.03 (.44)	4.20 (.50)
Couple	1.78 (.53)	2.05 (.56)	2.95 (.48)	3.05 (.58)
Girl with Toys	4.33 (.37)	4.15 (.53)	4.15 (.46)	4.18 (.49)
Tree	2.70 (.68)	2.53 (.75)	4.18 (.49)	4.03 (.62)

Two slides were used in each session. "Blackboard" and "Couple" were used in one session and "Girl with Toys" and "Tree" in the next. Thus each session had one slide with areas of saturated colour and one with fine detail. The two slides were shown alternately, but the test conditions were in random order, subject to the constraint that each test condition was shown twice for each slide. The picture produced by each test condition was shown for 20 seconds followed by 10 seconds of black. Each session lasted between 15 and 25 minutes.

Four extra presentations, giving a representative selection of test conditions,were added at the beginning of each session. Before each session the five observers were told that the first four presentations would be representative; they were then asked to grade all the presentations for picture clarity, including resolution and freedom from unwanted effects, using the CCIR quality scale:

1 Bad
2 Poor
3 Fair
4 Good
5 Excellent

The results of the first four presentations were ignored in the analysis; this allowed for the effects of observer adaptation. Also ignored were individual votes which differed by two grades or more from the mean assessment for that test condition, and votes where the two assessments by one person of the same test condition differed by two grades or more.

4.4 Results

The results of the first series of tests (which included clean coding and clean decoding via videotape) are given in Table 2 and plotted as histograms in Fig. 14. The results of the second and third series of tests, comparing conventional, notch and clean coders with a conventional decoder are given in Tables 3 and 4, plotted as histograms in

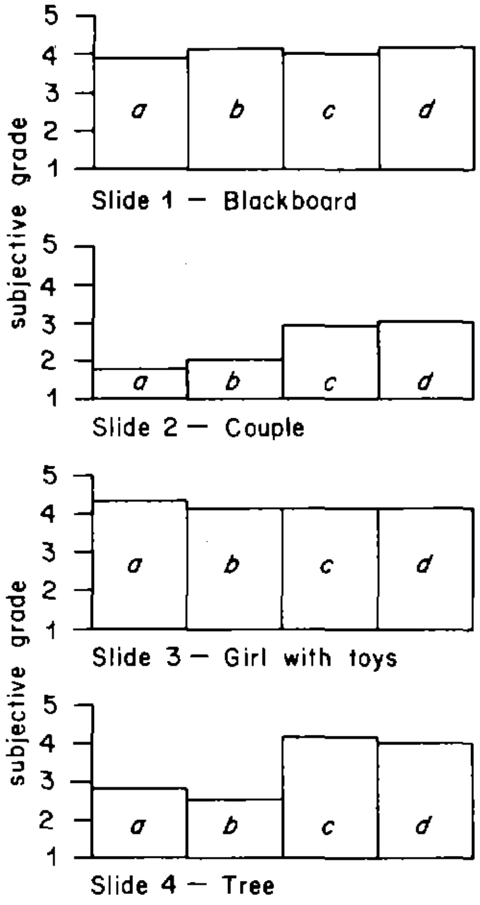


Fig. 14 - Results of test series 1 — colour

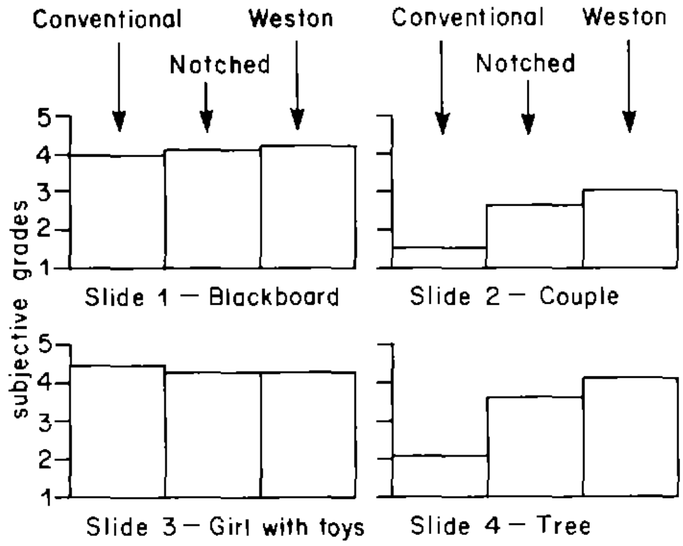
(a) conventional coding; conventional decoding
(b) conventional coding; clean decoding
(c) clean coding; conventional decoding
(d) clean coding; clean decoding.

TABLE 3
Results of test series 2 and 3 – colour
(averages of 20 observers; figures in parentheses are standard deviation)

Coder Slide	Conventional	Notch	Clean
Blackboard	3.95 (.60)	4.13 (.60)	4.22 (.44)
Couple	1.50 (.55)	2.68 (.49)	3.11 (.53)
Girl with Toys	4.34 (.64)	4.29 (.54)	4.29 (.63)
Tree	2.09 (.83)	3.58 (.73)	4.11 (.66)

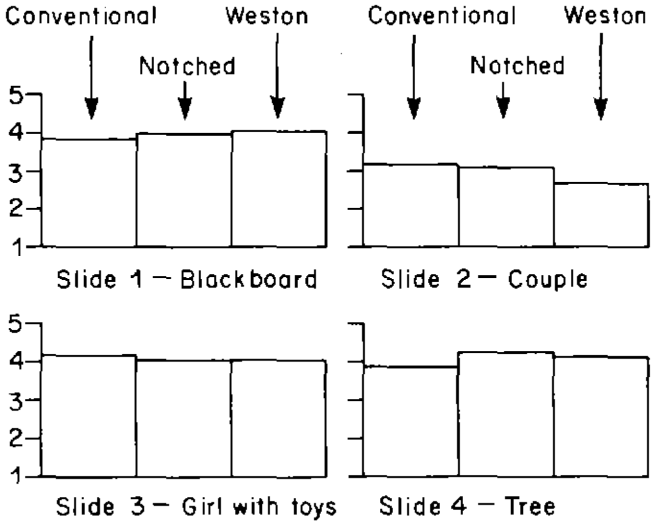
TABLE 4
Results of test series 2 and 3 – monochrome
(averages of 20 observers; figures in parentheses are standard deviation)

Coder Slide	Conventional	Notch	Clean
Blackboard	3.82 (.56)	3.97 (.68)	4.02 (.57)
Couple	3.18 (.55)	3.09 (.60)	2.66 (.63)
Girl with Toys	4.16 (.61)	4.04 (.64)	4.06 (.60)
Tree	3.83 (.64)	4.23 (.67)	4.15 (.68)



(a)

Fig. 15a - Results of test series 2 and 3 – colour.



(b)

Fig. 15b - Results of test series 2 and 3 – monochrome

Fig. 15. Since the different slides illustrate different aspects of the properties of coders and decoders, the results for the four slides are presented separately.

The results of Test Series 1, shown in Fig. 14 suggest that most of the benefit from clean PAL comes from the coder, which eliminates coarse crosscolour. On pictures with fine detail to cause crosscolour, clean coding makes a great improvement – about one grade on the slide "Couple" and about one and a half grades on the slide "Tree". But the grades for clean coding with clean decoding are little different from the grades for clean coding with conventional decoding. Similarly, grades for conventional coding with clean decoding are little different from grades for conventional coding and decoding.

With the other two slides, "Blackboard" and "Girl with Toys", which are more sensitive to chrominance effects, observers saw no significant differences between the various combinations of coder and decoder.

It is very difficult, when subjective tests give a "no difference" result, to know whether observers really saw no difference, or whether different impairments that they saw balanced each other out. For instance, does the "no difference" result between clean and conventional decoding, using clean coding, mean that observers did not see the fine crosscolour and loss of resolution caused by the conventional decoder? Or that they saw these defects, but balanced them against the alias components made visible by clean decoding? It may be possible to answer this question by using a high resolution monitor, to make the differences more obvious.

The results of Test Series 2 and 3, shown in Fig. 15, also present problems of interpretation. The monochrome results allow an assessment of picture sharpness on a display with higher resolution than a conventional shadowmask colour tube. Using the results of both colour and monochrome tests, it should be possible to say whether a notched coder or a clean coder gives better results.

For the two slides containing little high frequency detail to cause crosscolour or aliasing, "Blackboard" and "Girl", there is no significant difference between the systems in either colour or monochrome. It might be expected that the notched coder would be judged much better in colour because the clean coder has lower horizontal and vertical chrominance bandwidths, giving softer chrominance edges, and these two slides contain a lot of chrominance detail. But because of the lower horizontal chrominance bandwidth, the clean coder gives less subcarrier patterning on vertical chrominance edges, which subjectively balances the softening.

The two slides containing high frequency detail, "Couple" and "Tree", show up large differences between the coders. With colour pictures the clean coder was judged better by half a grade for both pictures. This is because the clean coder removes all coarse crosscolour, whereas the notched coder leaves some, since the notch is of limited depth. In monochrome, where high-frequency aliasing effects are no longer masked by a decoder notch filter, the clean coder was judged worse on the "Couple" slide by almost half a grade: this suggests that, in the absence of crosscolour, most people prefer soft pictures to aliasing.

Thus there are two effects working against each other: with conventionally decoded colour pictures, where aliasing cannot be seen, people prefer clean coding because of its freedom from coarse crosscolour; whereas in monochrome, where crosscolour cannot be seen, people prefer notch coding because of its freedom from aliasing – despite the loss of resolution, which is most obvious on the "Couple" slide. This conflict can only be resolved by testing a matched clean coding and decoding system, which retains both the aliasing and the freedom from crosscolour, against the matched system using a notched coder and a conventional (notched) decoder, without the uncertainty of an intervening videotape process.

5. Further work

Further work of two kinds is needed on the clean PAL system. Theoretical work is needed to determine the best forms of filters to be used in the system, and more extensive subjective tests will be needed.

In Section 3.2 it was pointed out that clean coding and decoding is free from crosseffects only if the bandpass filters used in the chrominance path are ideal. However, there may be other arrangements, using complementary filters, which would be more practicable. It is also possible to reduce the impairments – luminance aliasing and *U*/*V* crosstalk – by using higher-order filters, combining signals from more lines of one field or from lines of more than one field. This improvement would have to be paid for by the introduction of ringing on horizontal chrominance edges or by impairment of movement portrayal; a compromise would have to be arrived at giving the best subjective effect.

More rigorous subjective testing is also needed on the clean system. The tests carried out so far have used only four static slides. Further tests would be needed using a much wider range of test material, including moving pictures. These tests will have to wait until separate coder and decoder units are available. These tests should also use a high resolution colour monitor, to represent the higher resolution which may be available in colour television receivers of the future.

One aspect which will need careful testing is the effect of distortions in the transmission system. As explained in Section 4.3, complete elimination of crosseffects is possible only if the decoding phase is correct; a static phase error or differential-phase distortion will reintroduce both crosscolour and crossluminance. So testing of the clean system should include a simulation of a real transmission path.

6. Conclusions

Clean PAL coding and decoding is a better compromise than conventional coding and decoding between resolution and unwanted effects. It gives complete freedom from crosscolour and crossluminance and improved resolution of verticals at the expense of luminance aliasing, reduced vertical chrominance resolution and *U/V* crosstalk.

Clean coding removes coarse crosscolour, even when conventionally decoded; clean decoding of conventionally or clean coded signals removes fine crosscolour and removes crossluminance more effectively than a conventional decoder without using a luminance notch filter, giving sharper pictures. Thus clean coding and decoding are compatible with conventional decoding and coding.

The principal impairments from clean coding and decoding are the introduction of a luminance alias component and *U/V* crosstalk. The luminance alias component can be seen as a moving pattern in areas of fine luminance detail. The *U/V* crosstalk causes flickering on horizontal chrominance edges.

Preliminary subjective tests have shown that clean coding followed by conventional decoding gives a very worthwhile improvement to colour pictures compared with conventional coding because it removes coarse crosscolour. This conclusion applies even when the conventional coder incorporates a luminance notch filter to reduce coarse crosscolour. But there is some doubt about the added benefit of clean decoding, because it makes the alias components and *U/V* crosstalk more visible.

The clean coding and decoding scheme in this Report may not be subjectively the best possible clean PAL system; further work is needed to optimise the filters in order to reduce the impairments. Nevertheless it is likely that future improved PAL coding and decoding schemes will be based upon the principles described.

7. References

1. LENT, S.J. *and* REED, C.R.G. 1974. Reduction of cross-colour effects in PAL (System I) colour television by the use of low-pass and notch filters. BBC Research Department Report No. 1974/25.
2. LENT, S.J. 1972. The optimum characteristics for a simple luminance notch in a PAL colour television decoder. BBC Research Department Report No. 1972/7.
3. DREWERY, J.O. 1975. The filtering of luminance and chrominance to avoid cross-colour in a PAL colour system. BBC Research Department Report No. 1975/36.
4. AUTY, S.J., READ, D.C. *and* ROE, G.D. 1977. Colour picture improvement using simple analogue comb filters. BBC Engineering No. 108, December 1977.
5. WESTON, M. 1976. A PAL/YUV digital system for 625-line international connections. BBC Research Department Report No. 1976/24.
6. WESTON, M. 1979. Digital Y_2, $(U \pm V)$ – further tests. BBC Research Department Report No. 1979/5.
7. CLARKE, C.K.P. BBC Research Department Report to be issued in due course.
8. OSBORNE, D.W. *and* STOTT, J.H. 1979. Digital video: comb filtering in sub-Nyquist PAL codecs. BBC Research Department Report No. 1979/1.

APPENDIX*

1. Equivalence of the two forms of Weston decoder shown in Figs. 2 and 4.

Fig. A1 shows the Weston decoding process via $Y_2, (U \pm V)$, with the $2f_{sc}$ sampling process replaced by the addition of a PAL-modified bandpass filtered signal and the f_{sc} sampling process replaced by a demodulator and lowpass filter as described in Section 2.3. The sampler at f_{sc} and its associated lowpass filter may be replaced by a demodulator since the input is a bandpass signal. The phase relationship of the modifying and demodulating sinewaves is shown in the inset. The circuit may be divided into five filters, F_{11}, F_{12}, F_{21}, F_3 and F_4, as shown. The transfer functions of these filters can be seen by inspection to be as follows, neglecting the delays of the bandpass filters:

$$F_{11} = z^{-k} - F_{21}$$

$$F_{21} = \tfrac{1}{2}B(z^{-k} - 1)$$

$$F_{12} = 1 + F_{21}$$

$$F_3 = (1 + z^{-k}) / \sqrt{2}$$

$$F_4 = (1 - z^{-k}) / \sqrt{2}$$

In the above expressions, B is the transfer function of the chrominance bandpass filter, $z = \exp j\omega\, T_{sc}/4$ and $k = 1135$ so that z^{-k} is the transfer function of a line delay.

In the following analysis terms such as F^n

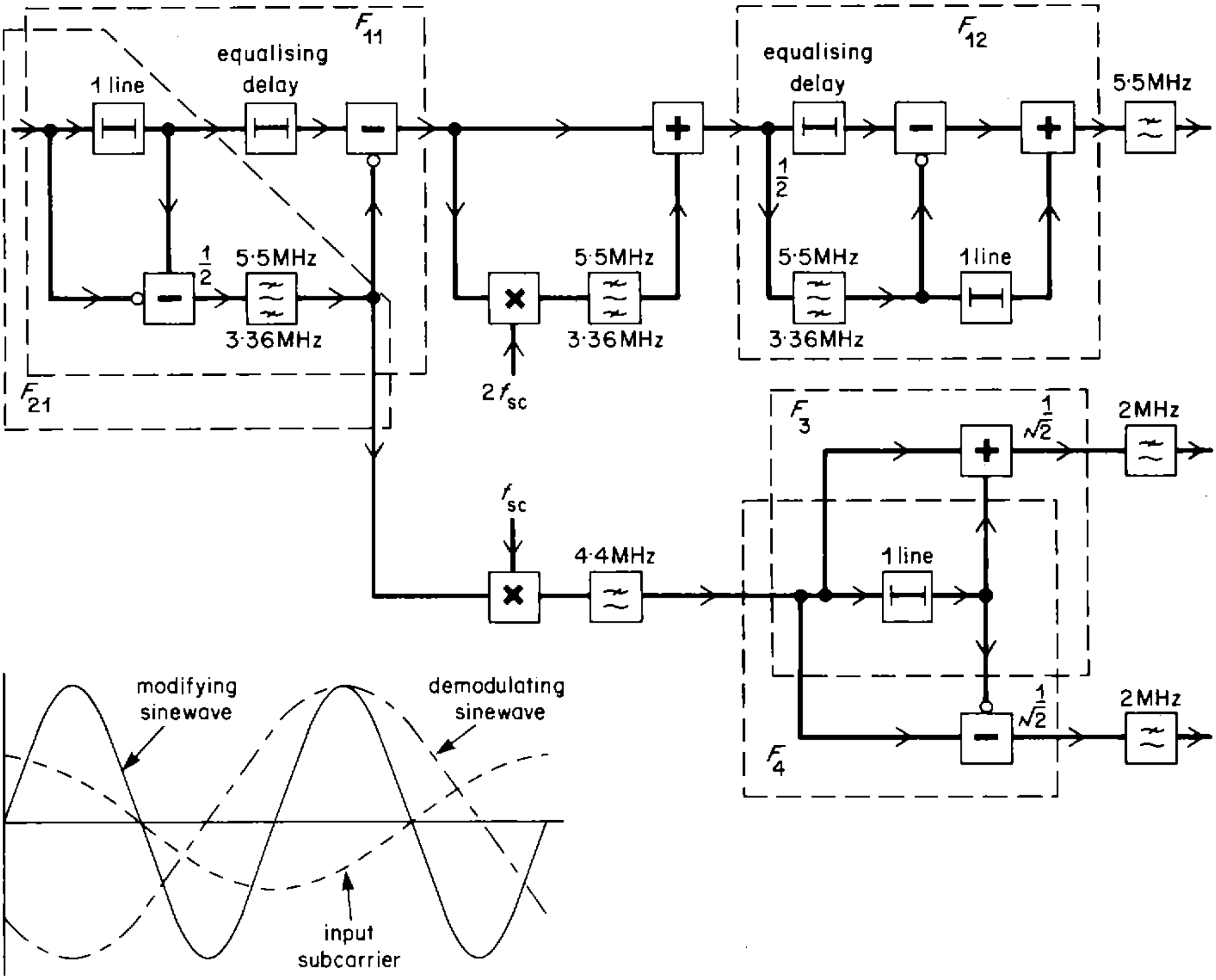


Fig. A1 - Weston decoding via Y_2, $(U \pm V)$, with the samplers replaced by multipliers.

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* By J.O. Drewery and A. Oliphant

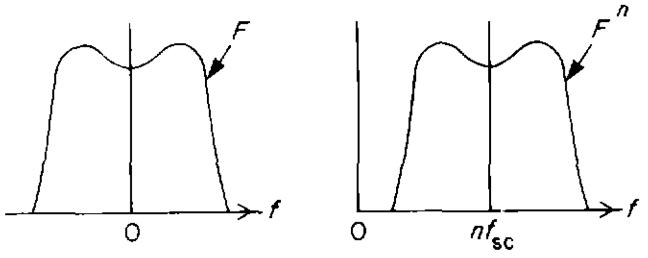


Fig. A2 - F^n as a shifted version of F.

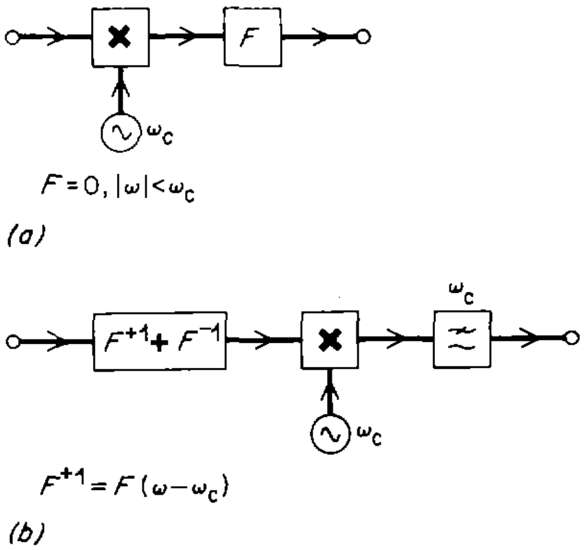


Fig A4 - Theorem 1. Transforming a post-multiplier filter into a pre-multiplier filter.

occur. This represents the transfer function of F shifted so as to be centred on nf_{sc}, i.e.

$$F^n = F(\nu - nf_{sc})$$

Fig. A2 shows an example. Normally such shifted functions occur in pairs, symmetrical about the origin, so as to represent realisable functions. A particular result we shall require is

$$(z^{-k})^n = j^{-n} z^{-k}$$

which is a consequence of the ¼ line offset of subcarrier frequency from line frequency.

Consider first the luminance path which bypasses the PAL modifier. The transfer function is $F_{11} F_{12}$ which is the simple cascading of pre and post comb-filters. This is well known to introduce a simple delay of one line at frequencies below the bandpass region and to take weights of ¼, ½, ¼ of adjacent lines at frequencies in the chrominance bandpass region. This is the transfer function of the filter shown in Fig. A3.

Now consider the path through the modifier. To obtain the required result we need to transform the filter F_{12} and place it before the modifier. To do this we make use of a theorem which states that the two circuits shown in Fig. A4 are equivalent, neglecting the group delay of the final filter in (b). That is, there always exists a pre-multiplier bandpass equivalent of a post-multipler filter, if it is of low-pass form cutting below the multiplying oscillator frequency. In the case of the Weston decoder the transformed filter is $F_{12}^{+2} + F_{12}^{-2}$ which must contain an implicit low-pass filter cutting below $2f_{sc}$. Fortunately this is a mild restriction and, since the modifier path contains a bandpass filter, we need consider only the frequencies within the pass region. For this region the transfer function of the transformed filter can be shown to be

$$\tfrac{1}{2}B\,(1 - z^{-k})$$

i.e. semi-differencing across a one-line delay.

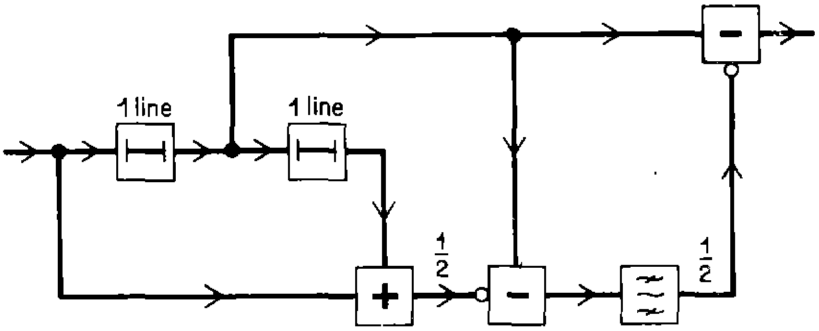
When this is cascaded with the filter F_{11} the resulting transfer function over the bandpass region is

$$\tfrac{1}{4}B\,(1 - z^{-2k})$$

i.e. quarter-differencing across a two-line delay. Thus the equivalent circuit of the modifier path is as shown in Fig. A5.

Finally, to achieve the required result and make the phase relationships more explicit we

Fig. A3 - Equivalent circuit of the luminance path bypassing the PAL modifier in Fig. A1.



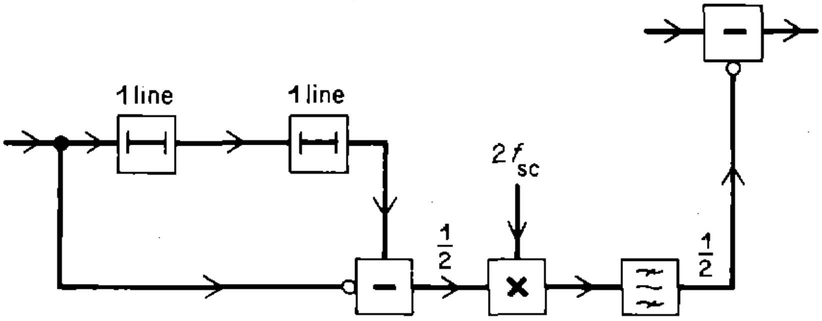


Fig. A5 - Equivalent circuit of the luminance path through the PAL modifier in Fig. 1.

may insert a 90° phase retardation after the subtractor and compensate by *retarding* the phase of the modifier by 90° (because we are selecting the lower sideband of the modifier output). This leads to the circuit of Fig. A6 where the phase of the modifier sinewave relative to the input subcarrier is shown in the inset. The phase of the subcarrier input to the modifier is now the same as that at the centre tap of the two line delays which is the reference point for chrominance cancellation and this subcarrier signal passes unchanged through the modifier.

The combination of Figs. A3 and A6 leads to

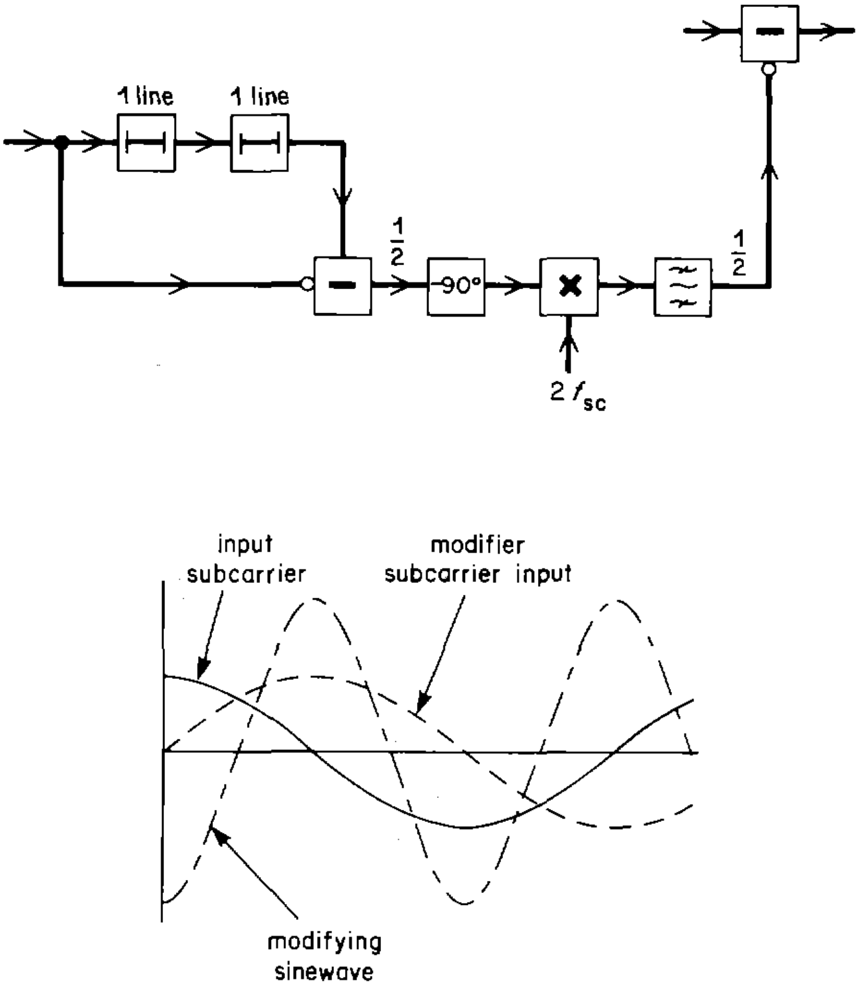


Fig. A6 - Correcting the phase relationships of the filter in Fig. A5.

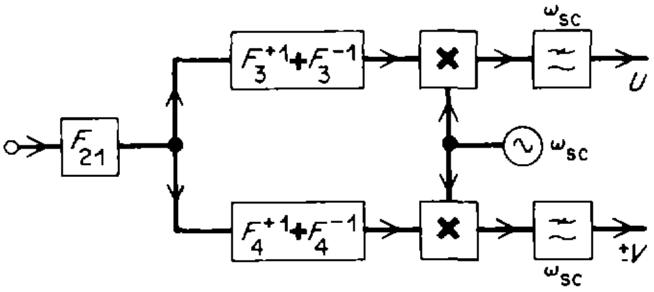


Fig. A7 - Equivalent circuit of the chrominance paths in Fig. A1.

the complete luminance path of Fig. 4.

Now consider the chrominance paths in Fig. A1. The above theorem may be invoked to transform the filters F_3 and F_4, yielding the equivalent circuit of Fig. A7.

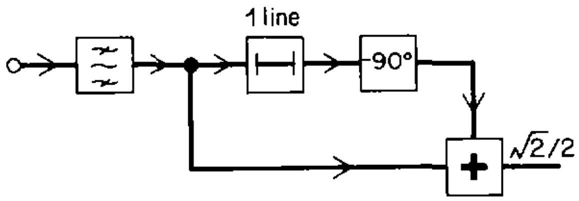


Fig. A8 - Equivalent circuit of the filter ($F_3^{+1} + F_3^{-1}$)

The filter $F_3^{+1} + F_3^{-1}$ can be shown to have a transfer function of

$$\tfrac{1}{2}\sqrt{2}\, B\, (1 - \mathrm{j}\,\mathrm{sgn}\,(\omega)\, z^{-k})$$

where B is the bandpass equivalent of the low pass filter, i.e. $B = (L^{+1} + L^{-1})$, $\mathrm{sgn}(x)$ is the signum function and $\mathrm{j}\,\mathrm{sgn}(\omega)$ is the transfer function of a 90° phase advance network. Thus the equivalent circuit is as shown in Fig. A8.

In the same way the filter $F_4^{+1} + F_4^{-1}$ has a transfer function of

$$\tfrac{1}{2}\sqrt{2}\, B\, (1 + \mathrm{j}\,\mathrm{sgn}\,(\omega)\, z^{-k})$$

so that the equivalent circuit has a 90° phase advance instead of a retardation.

When combined with F_{21} the resulting transfer functions are given by

$$F_U = \tfrac{1}{4}\sqrt{2} B[-1 + (1 + \mathrm{j}\,\mathrm{sgn}\,(\omega))z^{-k} - \mathrm{j}\,\mathrm{sgn}\,(\omega)\, z^{-2k}]$$

$$F_V = \tfrac{1}{4}\sqrt{2} B[-1 + (1 - \mathrm{j}\,\mathrm{sgn}(\omega))z^{-k} + \mathrm{j}\,\mathrm{sgn}\,(\omega)\, z^{-2k}]$$

whose realisations are shown in Fig. A9. At the U carrier frequency, for which $z^{-k} = \mathrm{j}$, F_U gives a phase shift of 135° corresponding to the demodu-

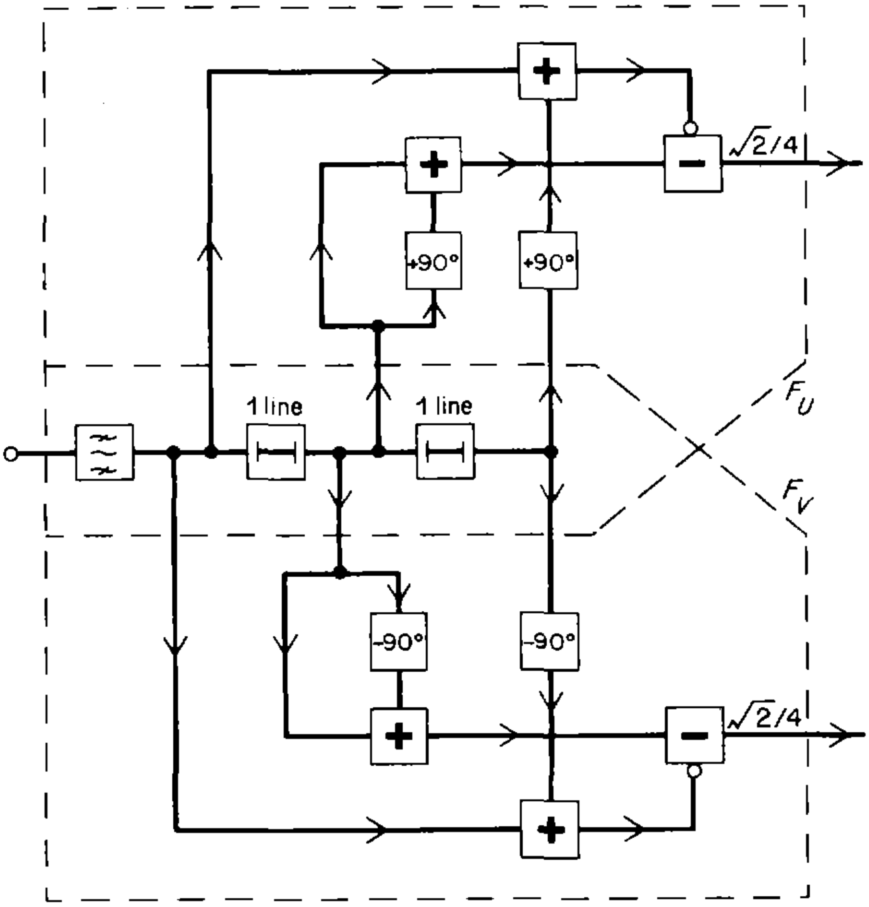


Fig. A9 - F_U and F_V.

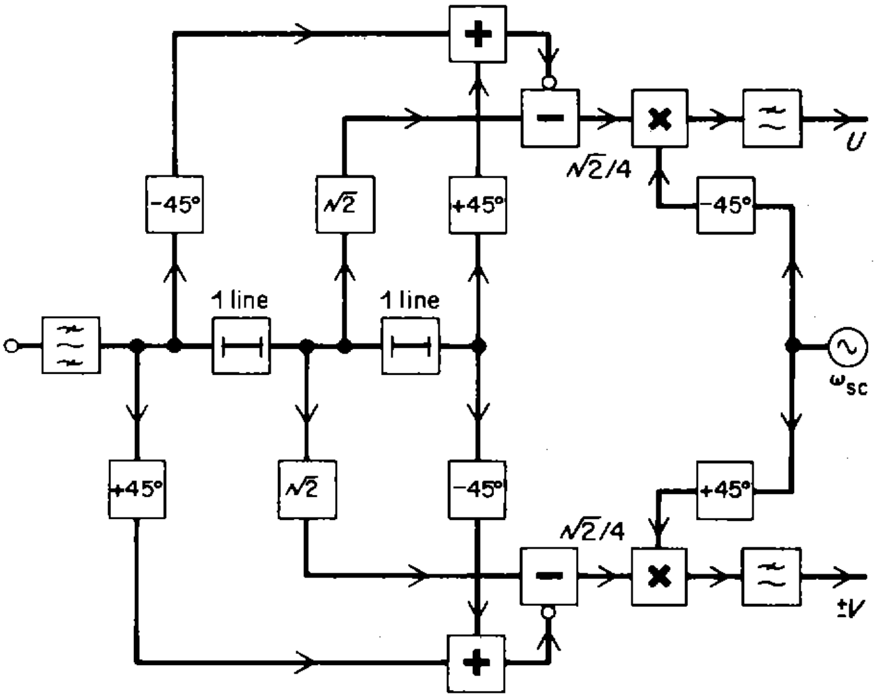


Fig. A10
F_U and F_V rearranged for quadrature demodulation.

lator phase shift in Fig. A1 whilst at the V carrier frequency, for which $z^{-k} = -j$, F_V gives a phase shift of −135°, bringing the quadrature input V signal into phase. The quadrature can be restored by extracting a 'factor' of +45° from the U filter and −45° from the V filter and demodulating in quadrature as shown in Fig. A10. We now have

$$F_U = \tfrac{1}{4} B\,[-H^*(\omega) + 2z^{-k} - H(\omega)\,z^{-2k}]$$

$$F_V = \tfrac{1}{4} B\,[-H(\omega) + 2z^{-k} - H^*(\omega) z^{-2k}]$$

where $H(\omega) = 1 + j\,\mathrm{sgn}\,(\omega)$

To proceed further we make use of another theorem which states that the two circuits in Fig. A11 are equivalent. For example, if $F_A = F_B = 1$ the equivalence is between quadrature demodulation of a single signal followed by quadrature re-modulation, and a bandpass filter, which is well known.

It follows from the equivalence of Fig. A11 and the fact that quadrature modulation followed by quadrature demodulation is equivalent to two 'straight connections' that the circuits of Fig. A12 are all equivalent. Fig. A12(a) is the equivalent of Fig. A10 which is transformed to Fig. A12(b) using cascaded quadrature modulation and demodulation and thence to Fig. A12(c) using the second theorem. The filters $\tfrac{1}{2}(F_U + F_V)$ and $\tfrac{1}{2}(F_U - F_V)$ are given by

$$\tfrac{1}{2}(F_U + F_V) = \tfrac{1}{4} B\,(-1 + 2z^{-k} - z^{-2k})$$

$$\tfrac{1}{2}(F_U - F_V) = \tfrac{1}{4} B\,j\,\mathrm{sgn}\,(\omega)\,(1 - z^{-2k})$$

The first of these takes weights of −¼, ½, −¼ of adjacent lines and the second takes a 90° phase shift of the quarter difference across two lines.

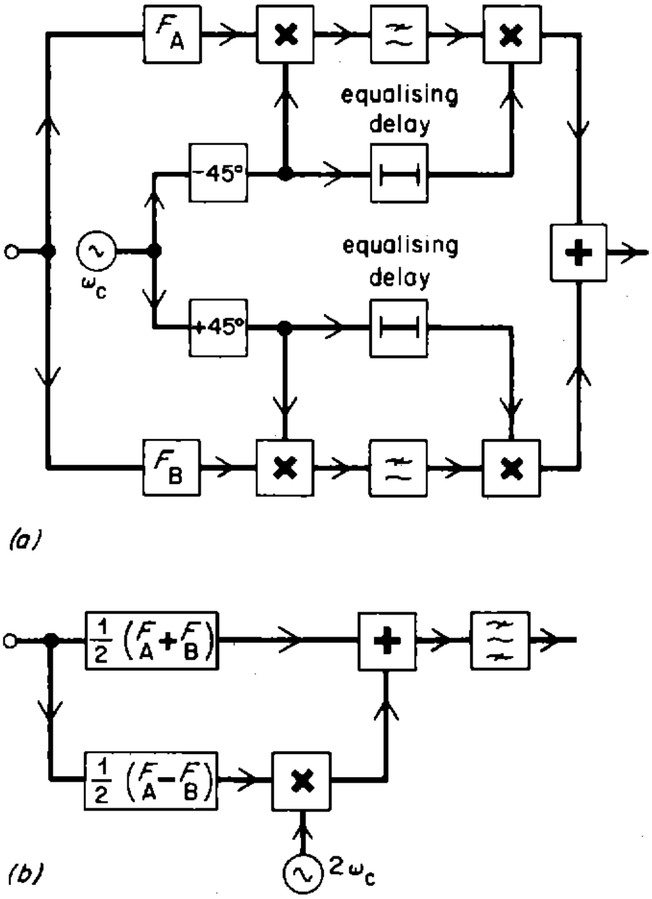


Fig. A11 - Theorem 2 equivalent circuits.

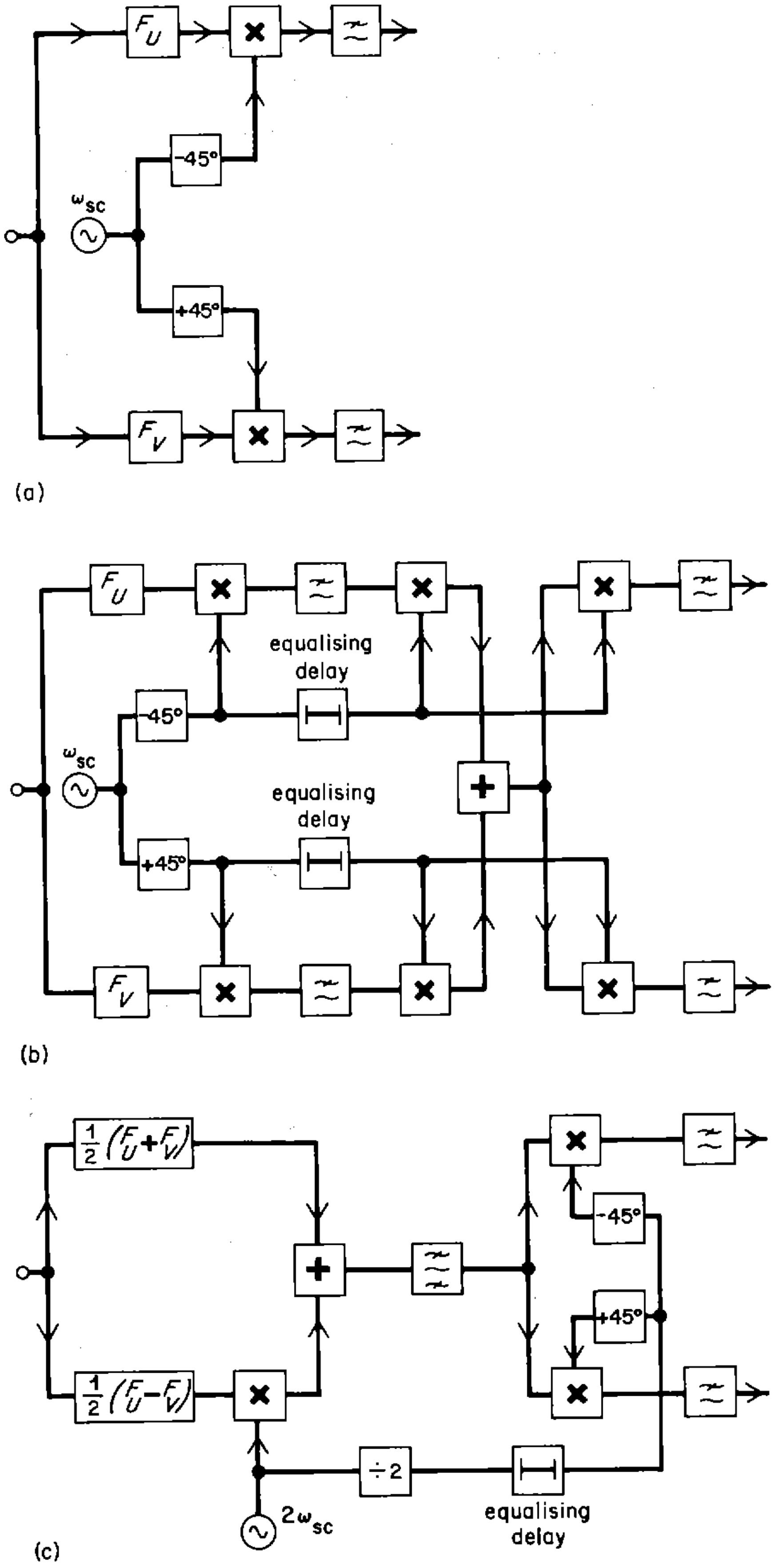


Fig. A12 - Rearrangements of Fig. A10

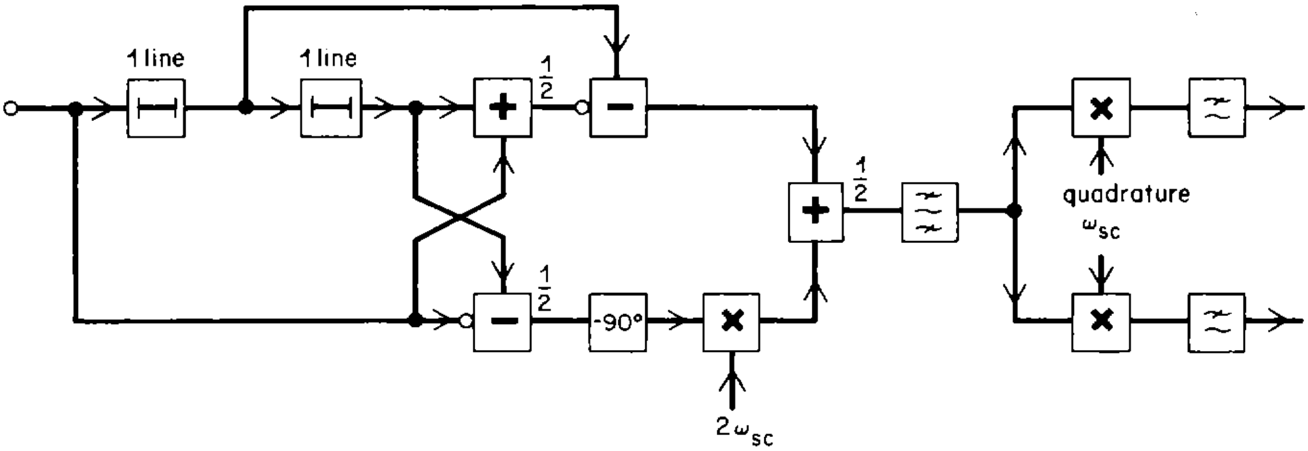


Fig. A13 - Chrominance equivalent circuit identical to Fig. 4.

Substituting these rearrangements into the circuit of Fig. A12 yields Fig. A13 which is identical to the chrominance paths in Fig. 4.

2. Matched coders and decoders.

It can be seen from Figs. 4 and 6 that the Weston clean decoder and coder are very similar. They are examples of a family of matched complementary coders and decoders.

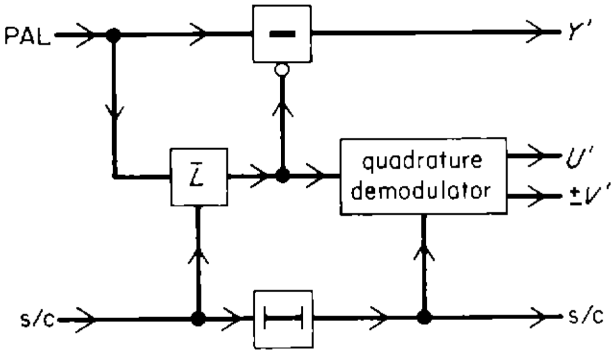


Fig. A14 - A complementary PAL decoder.

A complementary PAL decoder is one of the form shown in Fig. A14. A filter $\overline{L}$ (which may not be merely a passive network – it may contain a PAL modifier), stops information defined as luminance. The information which passes through the filter is assumed to be modulated chrominance and is quadrature demodulated to give U and V. The modulated chrominance is also subtracted from the original signal to give luminance.

Because of the use of a subtractor, the decoded luminance signal contains no information defined by the filter $\overline{L}$ as modulated chrominance. Thus the outputs are complementary, with none of the information in the original signal being lost and none duplicated in both channels. This does not mean however that a perfect separation of chrominance from luminance has been achieved, with no crosscolour or crossluminance; the amount of crosstalk depends on how good the filter $\overline{L}$ is at separating luminance from chrominance.

It may be noted in passing that the action of a complementary decoder can be reversed by a simple coder as shown in Fig. A15, provided the $Y'U'V'$ signals have not been processed in any nonlinear way and provided that the subcarrier

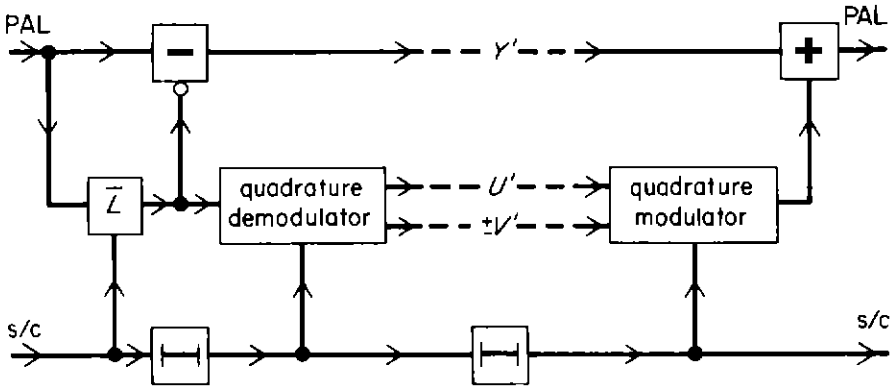


Fig. A15
A complementary PAL decoder can be reversed by a simple PAL coder.

phase and *V* switch relationship with the decoded signals are maintained. This reversibility follows from the fact that quadrature demodulation followed by quadrature remodulation is equivalent to a chrominance bandpass filter. This concept of reversible decoding is not of great use in practice because there is very little that can be done with the decoded signals without impairing the reversibility of the process.

From a complementary decoder, a matched coder can be constructed, using the same filter $\bar{L}$, as shown in Fig. A16. It is then possible to choose $\bar{L}$ so that there are no luminance-chrominance crosseffects when the matched coder and decoder are used together. The Weston coder and decoder described in this Report are one such matched complementary pair. Because of the reversibility of the Weston filters, a Weston decoder can be reversed by a Weston coder as well as by a simple coder. This is a special property of Weston coding and decoding which does not apply to all matched complementary coders and decoders.

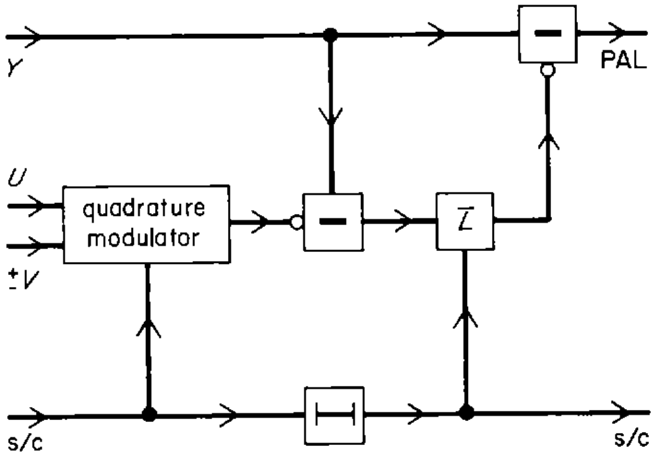


Fig. A16 - A complementary PAL coder matched to the coder of Fig. A14.

CJS/DS

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